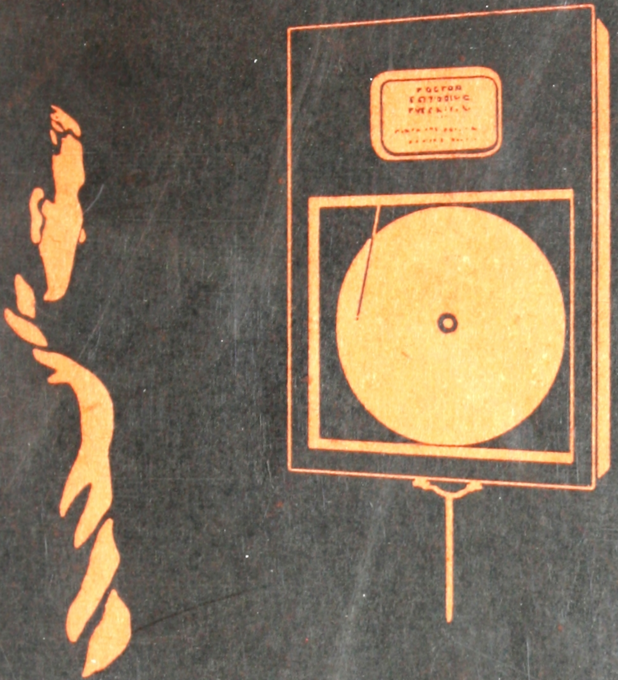

PRACTICAL PYROMETERS

BOOK No. 26

FOSTER INSTRUMENT Co.

LETCHWORTH, HERTS., ENGLAND

FOSTER INSTRUMENT Co.
LETCHWORTH, HERTS., ENGLAND.

FOSTER
PRACTICAL PYROMETERS

THERMO-COUPLE
(STEM) TYPE

Patented

"Designed by an Engineer for use by Engineers"

BOOK No. 26

Code Word Stellabas

On Lists of Admiralty, War Office, India Office, etc.

Head Office and Works: Letchworth, Herts., England.

Telephone: Letchworth 26.
Telegrams: "Foster Instruments, Letchworth".

Northern Depot: 9, Newton Road, Leeds.
Telephone: Chapeltown 474. Telegrams: "Instrument, Leeds".

Birmingham Depot: Queen's College, Paradise Street, Birmingham.
Telephone: Midland 2986. Telegrams: "c/o Yadall, Birmingham".

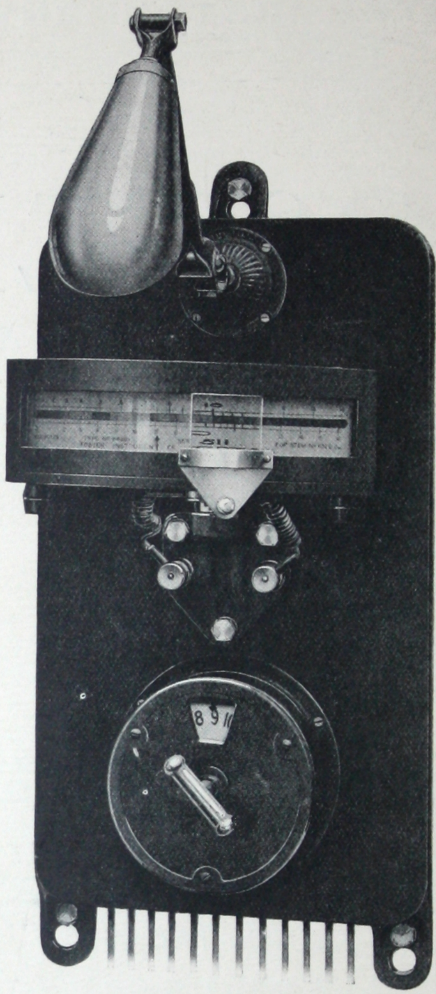

Fig. 1.

Foster "Resilia" Patent Wall Type Indicator, scale length 10 inches (254 mm.), with metal base, adjustable lamp bracket and lamp, also scale magnifier and enclosed rotary switch for twelve stations.

About $\frac{1}{6}$th full size.

FOSTER INSTRUMENT Co.
LETCHWORTH, HERTS., ENGLAND.

Foster Practical Pyrometers

THERMO-COUPLE (STEM) TYPE.

Patented in England and abroad.

Introductory.

In the present advanced state of technical knowledge in the matter of heat control it is hardly necessary to emphasise the need of a pyrometer for every important heating process; only by the systematic use of suitable pyrometers can good results be repeated and bad results avoided with certainty and regularity; consideration is rather given to the selection of the most suitable instrument for any given process. Careful study of the actual conditions under which industrial pyrometers have to work, based on statistics compiled over many years, has resulted in the success attained by FOSTER PRACTICAL PYROMETERS; they are "Designed by an Engineer for use by Engineers". The lessons of experience have been applied continuously to the improvement of details in the construction of the **thermo-couples, indicating and recording instruments.** The pyrometers described in the following pages embody the extensions and improvements resulting from experience in thousands of installations embracing hundreds of different industries. To make the details of each piece of apparatus clear at a glance the description is purposely brief, theoretical considerations leading up to the present designs are dealt with in separate notes at the end of the catalogue. See pages 27 to 39.

Simplicity and Robustness.

In all the various designs described herein, where alternatives offer themselves, the one giving the maximum simplicity and robustness has been selected. The temptation, natural to an enthusiastic designer, to embody ingenious contrivances and elaborations which are attractive academically, has been resisted and only those modifications adopted particularly leading to the production of a simple and robust industrial instrument. The fact that the main designs and characteristics of the instruments described here are broadly the same as those manufactured ten years ago needs no apology, it confirms the wisdom of the choice originally made.

Component Parts.

A **thermo-electric** or **thermo-couple pyrometer** for reading or recording directly in degrees of temperature comprises the following essential parts :—

(a) A **thermo-couple stem,** the tip of which comprises a junction between two different metals or alloys. When this junction is heated to the temperature to be measured an electric current is generated which actuates the **indicator** or **recorder.**

(b) A **compensating extension,** possibly with **cable** as well, to carry the current between the thermo-couple and the indicator or recorder.

(c) An **indicator,** in which a pointer moves over a scale and points to the temperature of the junction of the thermo-couple; or a **recorder,** in which a pen registers automatically on a chart, thus making a continuous and permanent record of the temperature.

Two Classes of Pyrometer.

FOSTER PRACTICAL PYROMETERS are in all cases designed to give the most efficient performance under the circumstances existing in the industry concerned. In those cases where the installation may be a simple one, advantage is taken to make it of maximum robustness. In such cases the component parts are all standardised on an interchangeable basis and the pyrometer is made up as a **" unit ",** thus securing the greatest simplicity with consequent low cost in installation and upkeep. In the **" Unit " class** the requirements as to care in use are reduced to a minimum, the design securing the advantage of a " high torque " instrument without any sacrifice in practical accuracy. A **wall type indicating outfit** of the **" Unit " class** is illustrated in Fig. 2 below.

It is always desirable to use the " Unit " class wherever possible, but there are cases which demand a pyrometer allowing wider flexibility in the conditions of use. For such cases a **" high resistance " instrument** is made. The explanation below shows briefly the considerations upon which the choice should be based; free advice on this and other matters will be given, see page 26.

" Unit " Class Pyrometers.

This class is designed for thermo-couple stems of standard types and lengths, " compensating extensions " of known length, not more than 30 feet (9.2 m.), cables of known lengths, not exceeding 100 feet (30 m.) twin, in any one line, and indicators or recorders having " high torque "—that is, with operating and controlling forces so large that the instruments can withstand the rough usage often unavoidable under industrial conditions. The use of the **Hoskins' base metal thermo-couple alloys,** patented thermo-couple construction, and special **spring jewel mounting** embodied in the design result in pyrometers in which the qualities of mechanical robustness are given paramount importance, see theoretical notes, pages 27 to 39.

" High Resistance " Pyrometers.

Where it is desired to use **" base metal " thermo-couples** of great or varying lengths or **" rare metal " thermo-couples** of any length, " compensating extensions " and cables whose lengths or

resistances are beyond the standards suitable for the **"Unit" class,** and also where more than one instrument may be connected, at the same time, to one thermo-couple, **"high resistance" instruments** are specially suitable. These have an electrical resistance sufficient to secure high accuracy under the conditions above, yet, by virtue of a new patented **"Resilia"** design, a robustness is secured which makes them thoroughly reliable industrial pyrometers, the power of withstanding mechanical damage and vibration is greater than that possible with any apparatus not embodying the special patent **"Resilia"** features. An indicator of the **"high resistance"** class is shown in Fig. 1 (frontispiece).

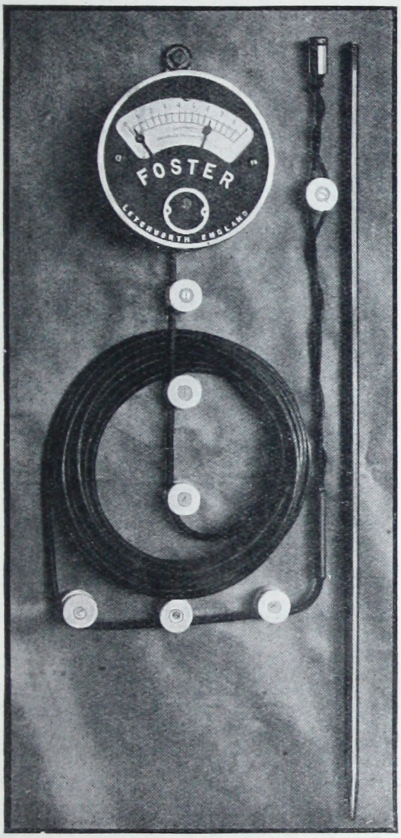

Fig. 2.

Wall Type Indicating Outfit, "Unit" Class.

Ease of Reading.

In all cases the scale of the indicator or the chart of the recorder is arranged to facilitate reading at a glance, the temperature can be read as easily as the time on a clock. Examples of standard scales and charts are shown in Fig. 19, on an extending sheet at the end of the book.

Thermo-Couple Stem.

As indicated on page 4, under "a", the thermo-couple or stem comprises two alloys joined together at the tip, the heating of the tip generating an electric current ; the more the tip is heated the greater is the current. The alloys comprised in the stem may be the relatively cheap " base metal " alloys—for instance, the Hoskins' alloys—in which case the wires are of large cross-section, diameter at least ⅛ inch (3 mm.) and therefore mechanically strong ; or, alternatively, of " rare metal "—for instance, platinum *v.* platinum-rhodium—in which case, of course, owing to the greater cost, the wires are of relatively small cross-section, the best compromise between cost and mechanical strength being diameter one fiftieth inch (0.5 mm.).

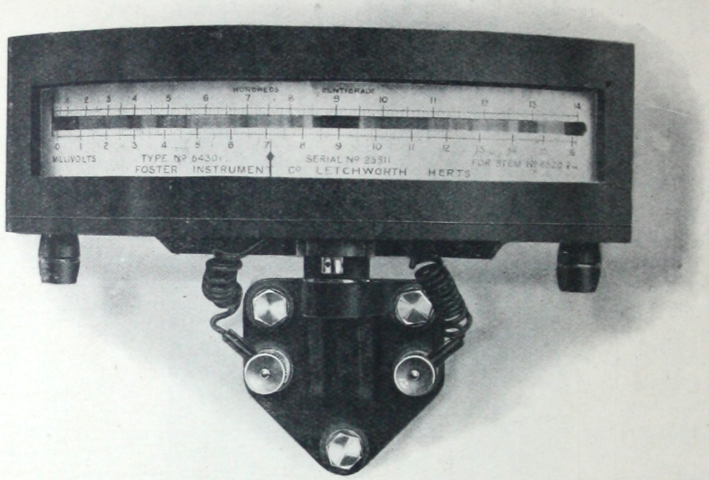

Fig. 3

Wall-Type Indicator, "Resilia" Patent, 10 inch scale, with Swivel Bracket

Tube Type " Base Metal " Stem.

For temperatures not usually over 950° C. (1706° F.) and which never exceed 1050° C. (1922° F.), a patent construction embodies the two thermo-couple alloys in a tube outside diameter ⅝ inch (16 mm.), so that the whole **stem** is convenient to handle, being a single unit or " rod ". Renewal of the **stem** is a matter of seconds only. An example is seen on the right of Fig. 2, page 5, the usual standard length being 36 inches (914 mm.).

Wire Type " Base Metal " Stem.

For higher temperatures, particularly above 850° C. (1562° F.), and up to a maximum of 1300° C. (2372° F.) for short tests, the two alloys are in the form of thick wires of diameter ⅛ inch (3 mm.) of **Hoskins' " chromel alumel "** each covered with stout insulating sleeves, the whole forming the " stem ". The wires are attached to the **head,** which is weatherproof and provides connection to the rest of the pyrometer circuit ; they may be detached therefrom and renewals inserted in a few seconds without breaking

or making any soldered joints. Renewal costs are reduced to a minimum, the insulating sleeves are often available again, when only the two wires, joined together at the tip, are needed for renewals. This type is illustrated in Fig. 4 below, where it is shown with and without a sheath, the renewal wires, covered by insulating sleeves, being shown separately.

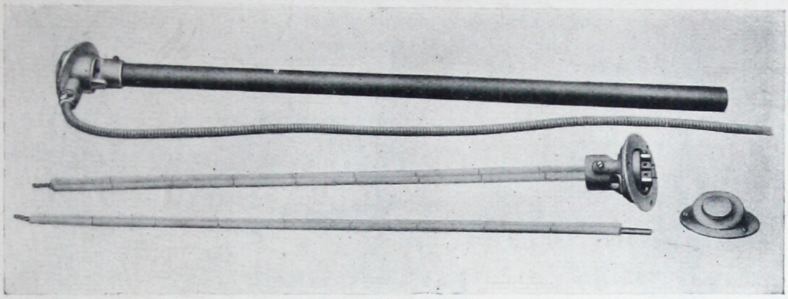

Fig. 4
"Wire Type" Base Metal Thermo-couple Stem, with Head and Compensating Extension.

Wire Type "Rare Metal" Stem.

The temperature ranges and conditions for which a **"rare metal" thermo-couple stem** is suitable are broadly indicated in the theoretical notes, pages 27 to 39. The FOSTER PRACTICAL PYROMETER of this type is arranged for quick and easy attachment of the stem to the head which is similar to the head used with the **wire type "base metal" stem.** The wires at the fused "hot junction" and for a length of 12 inches (305 mm.) therefrom are sealed in a special silica (quartz) protection sleeve, the upper portion of the wires being covered and insulated by single silica sleeves, the whole forming the "stem". A **"rare metal" stem** with head and, separately, a protecting sheath, are shown in Fig. 5 below.

Fig. 5.
Wire Type Rare Metal Thermo-couple Stem, Platinum v. Platinum-Rhodium, with internal insulation and Sheath.

Sheath.

For the protection of the thermo-couple stem an outer sheath is frequently desirable; for instance, where the temperature to be measured is high or where the stem is exposed to the destructive action of gases, molten salts or metals. The requirements of the protecting sheath vary with the process to which the pyrometer is applied, but in every industrial case the "base metal" alloys

require only the simplest, cheapest and most robust kind of protection. In the case of the "rare metal" alloys it is essential that the protection shall be gas-tight, see theoretical notes pages 27 to 39.

For the "base metals", at the lower ranges of temperature, say up to 850° C. (1562° F.), sheaths of welded steel or cast iron are used; the mechanical strength is therefore high and the

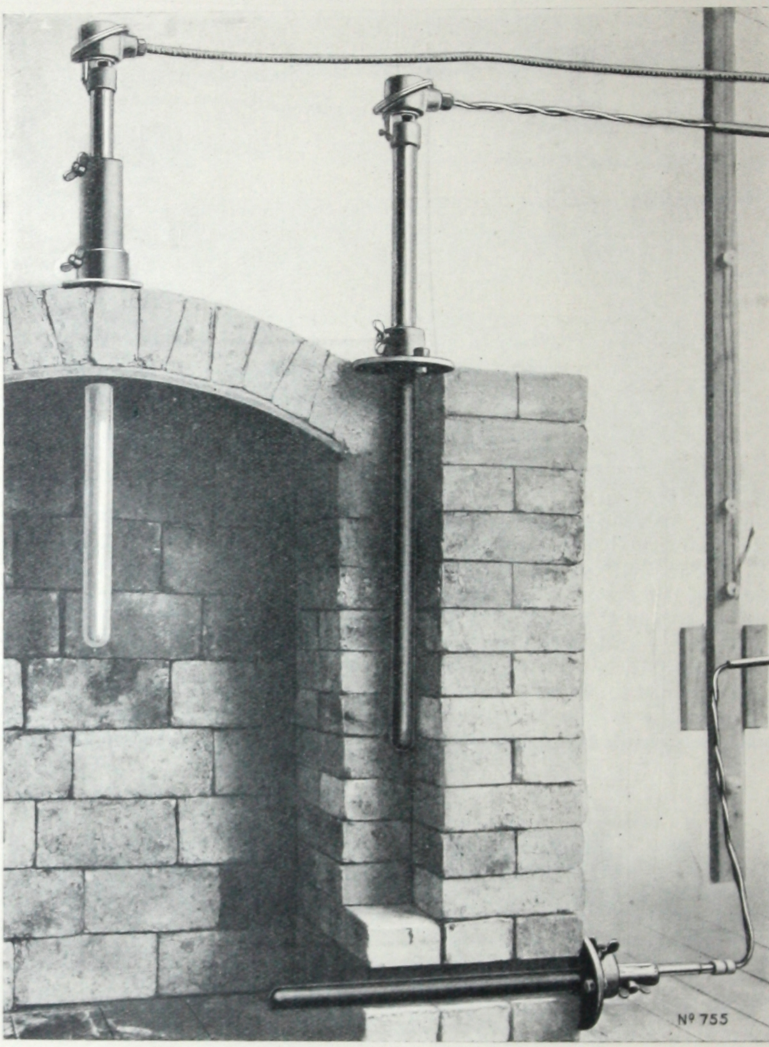

Fig. 6

Examples of Foster Base-metal Thermo-couple Stems with Sheaths, Flanges and Extensions.

replacement cost low. To extend the advantages of a metallic sheath to higher ranges of temperature, say up to 1000° C. (1832° F.) a special sheath, of which the portion exposed in the furnace is cast in **Hoskins' nickel chromium alloy,** is provided with an upper portion not inserted in the furnace, of steel. These special sheaths give long service under severe conditions.

For "rare metals", as indicated above, it is essential that the protection shall prevent the penetration of furnace gases or metal vapours. The only two practicable alternatives are fused silica (quartz) up to 1100° C. (2012° F.) or a fine grade of porcelain externally glazed up to 1400° C. (2552° F.). Both of these materials are unavoidably fragile, therefore, for industrial furnace work, to reduce the length of the fragile material the sheath is compound, that portion not subjected to high temperature is of steel, thus reducing the chance of breakage and decreasing the cost of renewal if it should be broken. Examples of these industrial sheaths are shown in Figs. 4, 5 and 6, and in Figs. 17 and 18 on extending sheets at the end of the book, with appropriate flanges or other fittings for attachment to the furnace etc. See also "Examples of Application", pages 19 to 25.

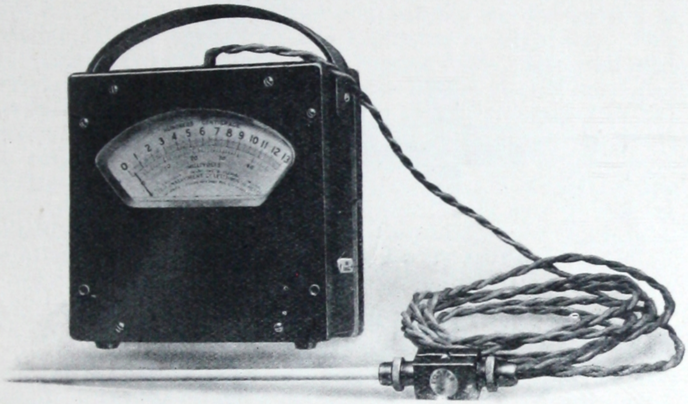

Fig 7

Laboratory Type Portable Indicating Pyrometer.

Laboratory Type Stem.

The conditions for laboratory work usually require a sheath of small diameter. A special form is made, outside diameter $\frac{5}{16}$ inch (8 mm.) of fused silica (quartz), the usual standard length being 12 inches (305 mm.). The head in this case is made specially light, and allows quick attachment or replacement either of the sheath or of the thermo-couple wires. It is illustrated in Fig. 7 above.

Connection.

Great attention has been given to the details of the electric circuit connections, because the accuracy of a thermo-couple pyrometer depends upon certainty and uniformity of contact. The points in the circuit where it may be separated are made as few as possible, continuous circuits, with carefully soldered joints, being used for the permanent parts. Where separation is needed—as, for instance, between the tube type stem and the rest of the circuit, for renewal of the stem—a "**connector**" of special design is used. The experience of very many years has shown the advantages of this design; it is concentric, of a "Union" type, giving quick and certain contact, in which reversal of connection or unscrewing by vibration or tension on the cable is impossible. In the wire type stem the head itself provides the connection in a convenient manner.

Compensating Extension.

It is desirable, in all thermo-couple pyrometers, that the **"cold junction"**, where the thermo-couple alloys join the rest of the circuit, should be at a steady low temperature and uninfluenced by any change in the temperature of the furnace wall; this **"cold junction"** forms the "datum line" of the measurement of temperature. To secure this condition, and at the same time to make the stem renewals short and cheap, a **compensating extension** is used, composed of alloys similar to those in the stem. In effect, the **compensating extension** is part of the thermo-couple, and its length should be sufficient to remove the "cold junction" from the direct influence of the furnace heat.

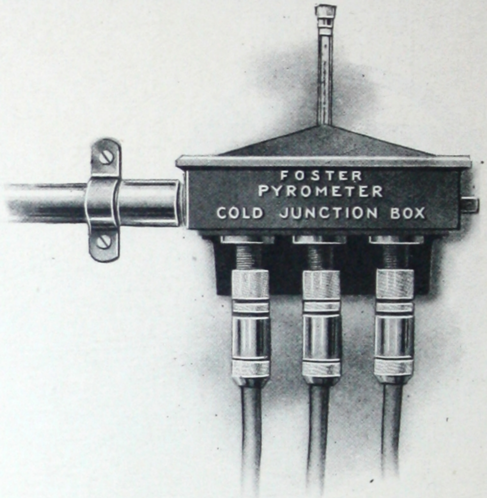

Fig. 8
Three-way "Cold Junction" Box.

In wall type indicating or recording outfits of the "Unit" class, for fixed use, the simplest standard extension is 2 feet (61 mm.) long and is semi-flexible. At the "cold junction" it is permanently soldered to the cable leading to the indicator or recorder. Alternatively, the extension may be in multi-strand flexible form. In such a case the extension may be protected by flexible metallic tubing. It may be attached directly to the cable or fitted at the "cold junction" with a **connector** which is attached to a cold junction box, described below. In this latter form the extension is instantly detachable for renewal or repair, and the cable may be run in conduit. Extensions for the "Unit" class may be of any prescribed length up to 30 feet (9.1 m.).

In the case of "high resistance" outfits the extensions may be practically any length required by the conditions, and may be arranged and connected as described for "Unit" outfits, or it may extend right to the indicator or recorder.

Portable indicators are usually only required with relatively short connections; in the "Unit" class the standard extension is multi-strand flexible, of length 10 feet (3 m.), attached directly to the indicator. Examples of the extension are shown in Fig. 6, page 8, also Figs. 17 and 18 at the end of the book. See "Examples of Application" pages 19 to 25, and theoretical notes pages 27 to 39.

Cold Junction Box.

In cases where the **flexible compensating extension** is required to be well protected in the neighbourhood of the furnace, it is, as indicated above, conveniently encased in **flexible metallic tubing.** In order to allow of the easy replacement or repair of that portion of the extension adjacent to the furnace it is fitted also, at the end remote from the thermo-couple stem, with a **concentric connector** making connection to a **cold junction box**; it is therefore quickly detachable. In this box the actual cold junction is made by soldered joints dipping into an oil bath. A thermometer, suitably protected, has its bulb in the same oil bath and its scale arranged to be read easily above the cover of the **junction box.** The whole junction box is weatherproof and adapted for attachment to 1-inch heavy screwed conduit for the protection of the remainder of the circuit to the indicator or recorder. This circuit, in "Unit" outfits, would be in copper cable; alternatively, in "high resistance" outfits the remainder of the circuit may also be compensating extension, in which case the thermometer in the cold junction box is not required. Cold junction boxes are made for single cold junctions or, alternatively, for three in one box, as, for instance, for three separate thermo-couple stems in one furnace or, alternatively, in three adjacent furnaces. Fig. 8, page 10, illustrates a three-way cold junction box. See "Examples of Application", Stations 11 and 14, pages 23 to 24.

Cold Junction Stand.

For use in experimental and laboratory work, particularly where small furnaces and laboratory type stems are used, it is desirable to keep the cold junction steady at a temperature which may be easily ascertained, and for this purpose the **cold junction stand** illustrated in the front of Fig. 11, page 16, is made. The thermo-couple itself or a compensating extension therefrom is brought to two double terminals mounted on the back of a double shield in a position remote from the furnace and therefore unaffected by radiated heat. From these terminals a short compensating extension extends to the cold junction in an oil vessel into which the bulb of a mercury thermometer also dips. With this arrangement it is easy to keep the cold junction at a steady known temperature throughout the duration of an experiment without the trouble and complication of an ice vessel or hypsometer.

Cable.

The standard cables are twin, heavily protected, suitable for industrial use. For fixed installation they are stranded sufficiently to make them semi-flexible and suitable for drawing into conduit. Where conduit is not to be used, insulators and screws are supplied to hold the cable permanently. For portable use the cables are multi-strand fully flexible, and may be supplied, if desired, in flexible metallic tubing. In every case the size of the cable is sufficient to combine mechanical strength with low electrical resistance, see theoretical notes pages 27 to 39. "Common return" wiring is not recommended, and should never be used because it involves the possibility of error due to accidental "earths" or connections not intended in the scheme; the saving in copper cable is relatively small and is not warranted in view of the risk of inaccuracy which is involved.

Indicators and Recorders.

In the FOSTER PRACTICAL PYROMETERS the design has been kept particularly simple in order to achieve the maximum robustness and reliability under industrial conditions. In the "Unit" class the robustness is secured by relatively very large moving forces, so that small effects of friction due to wear or misuse are negligible in their effect upon the reading. On the other hand, in the "high resistance" class the forces are necessarily smaller, but advantage has been taken of the special patented "**Resilia**" design, whereby the instrument is, nevertheless, able to withstand industrial conditions. The description immediately below relates to the "Unit" class instruments, the description of the corresponding "**Resilia**" instruments of "High Resistance" being on pages 15 to 17.

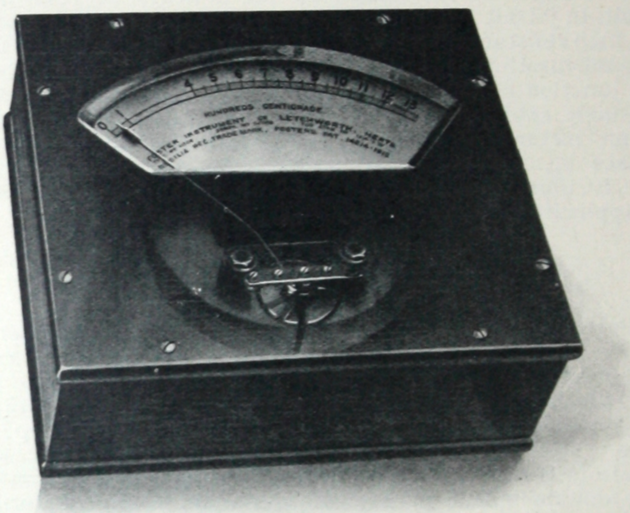

Fig. 9
"Resilia" Patent Portable Indicator, "High Resistance" Class.

"Unit" Class Indicator.

For use in a fixed position the **wall type indicator** is made. The metal case is robust and adapted for fixing on a wall, with the scale vertical, so that the temperature may be read as easily as the time on a clock dial. An **adjustable red index** is provided, which may be set to point to any desired temperature, the user can thus see at a glance, and from a distance, whether that temperature is maintained. This **adjustable red index** is seen in Fig. 2, on page 5, set at 650° C. For work in which the instrument must be carried from place to place, a **portable indicator** in a polished hard-wood case, with leather carrying handle, is made, thus reducing the weight and giving the most suitable protection from jolting and from sudden change of air temperature. This indicator is illustrated in Fig. 7, page 9. For heavy industrial use the flexible compensating extension may be protected, if desired, by flexible metallic tubing.

The scale is boldly divided and figured, and the pointer is large, so that the temperature may be read with ease even in a poor light. The length of the scale is 5 inches (127 mm.), which is found a convenient size for general industrial use. For **" high resistance Resilia " indicators,** see pages 15 to 16.

" Unit " Class Recorder.

The FOSTER PATENT AUTOMATIC RECORDER is used when continuous records are desired. The temperature may be read at any moment without disturbing the instrument; it therefore serves also as an indicator in addition to providing a permanent record. By installing a recorder where it can be seen by the furnace man it is found that remarkably regular firing can be maintained, the furnace man judges, by the slope of the record line, whether the temperature is changing slowly or quickly, and regulates the furnace accordingly.

The pen is controlled by a moving system generally similar to that in the indicators, with corresponding robustness; there is no suspension wire to break. Instead of moving a pointer over a scale it moves a pen and pen arm over a chart. In order to avoid the errors which would result from friction if the pen were constantly pressing upon the surface of the chart, and also to avoid smudging of the record, which might arise under the same circumstances, the pen is normally out of contact with the chart, but is pressed thereon once each minute, leaving an indelible ink dot. Having made a dot upon the chart the pen is deflected to the side of the case and is then pressed upon an ink drum, thus receiving a fresh supply of ink for the next dot. In this manner a chain of dots is made upon the chart, these dots joining up into a continuous line with normal working. See sample chart, Fig. 19, at the end of the book.

The chart is rotated by a clock mechanism, the same mechanism being employed to deflect the pen to the ink drum and to press it upon the drum and subsequently upon the chart. The circuit from the thermo-couple stem is never broken and there are no other electric circuits whatever in the recorder, there are no " make and break " contacts or electro-magnets, and there is, therefore, nothing in the instrument which cannot be seen, inspected and adjusted by the user. The clock mechanism is specially designed and made in the Foster Instrument factory for this recorder. The design is such that it is suitable for work under severe industrial conditions where more delicate and complicated instruments would be likely to break down. The case is fitted with a dust seal, the moving system and clock are separately protected inside the main case, the whole being damp-proof and insect-proof, and therefore well suited to tropical and other export conditions. The recorder hangs vertically on a wall as shown in Fig. 10, page 14. For **" high resistance Resilia "** recorders see page 17.

Recorder Chart.

Since the whole function of a pyrometer recorder is to produce a chart which shall be permanent and easy to read, the chart itself has been the subject of special study. The paper is stout and specially prepared; it is practically imperishable, no loading of the surface being allowed. The printing is clear, well subdivided, and of a colour giving a convenient contrast to the actual record line. Both the record line and the printing of the **chart** are indelible, in fact, the whole chart might be dipped in water

without affecting the permanency of the record. The record may be seen and inspected and the temperature read from the recorder at any moment without disturbing its operation. The chart being circular, the whole of the record can be seen at a glance without disturbing the recorder in any way, this is not possible with a drum type instrument. The chart is arranged to rotate once in twenty-four hours, but where desired specially the recorder may be allowed to run over several days, as, for instance, in recording a temperature which rises slowly to a maximum, remains steady for a period and then falls slowly. A small portion of the chart is reproduced in Fig. 19 on an extending sheet at the end of the book, but for convenience is there printed in black instead of the special colour used in the actual chart. It will

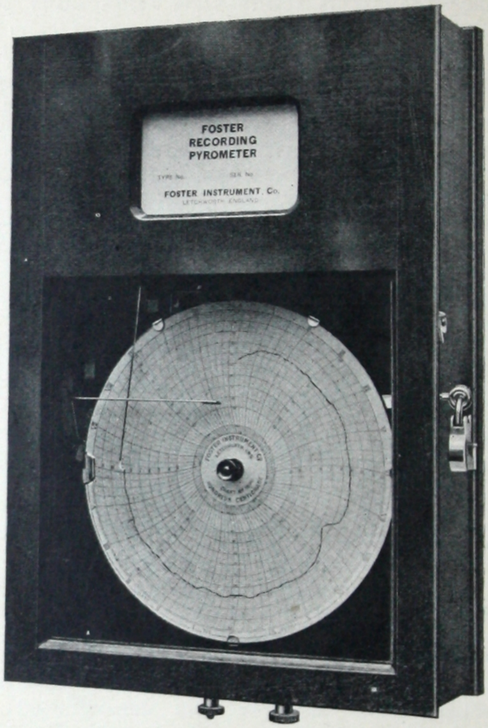

Fig. 10

Foster Patent Automatic Recorder.

be seen that the time scale is an open one over the upper part of the range of temperature for which the instrument is designed, and the chart being circular it is in a more convenient form for a given time scale than would be the case with a drum. The attachment and removal of the chart is an operation of only a few seconds; it has been so simplified that the ordinary furnace man can change the chart with ease. When the door of the recorder is opened, the pen and pen arm are automatically lifted off the chart and carried to the left, to protect them from damage when inserting a new chart, and they are held out of the way until the door is closed again; having a central hole, the chart may be filed very easily for reference afterwards. On each chart there is provision for writing the date, furnace number and job in hand. The standard ranges are given in the table on page 19.

Operation Recording Punch.

It often happens that it is desirable to record on the chart the time when some operation was performed—for instance, when the furnace was fired, when it was charged, when the heat was cut off and the furnace man left. This is conveniently done by fitting an **operation recording punch.** The pressing of a button at the side of the case punches a small triangle in the margin of the chart exactly opposite the time when the button was pressed.

Automatic Alarm.

The recorder may be fitted with an **automatic alarm** whereby a bell is rung when a given temperature is exceeded. The **alarm contact** may be set to any desired temperature, and when this temperature is reached the bell is rung intermittently for about ten seconds every minute until the temperature again falls below the pre-determined figure. This intermittent action is particularly advantageous in calling the attention of the operator. If desired, the **alarm contact** arrangement may have two contacts whereby a bell is rung when the temperature rises above or falls below certain narrow limits. It is then called a **"double alarm"** in distinction from the **single alarm** described above. **Either double** or **single alarms** may be set by the user to any desired position on the temperature scale.

Attempts have been made by various makers to apply alarm contacts (or automatic control, see below) to indicators, but if the deflecting force only of the indicator is relied upon to make the necessary contact it is found to be insufficient and therefore the arrangement is unreliable. If a clock or other mechanism is added to the indicator in order to supply satisfactory force for making the desired contact, then the apparatus involves practically all the component parts included in a recorder, except the actual pen and chart. This being so, it is obviously preferable to apply the alarm mechanism to the recorder and thus to have also the advantage of the automatic record.

Automatic Control.

The same mechanism, described above for the alarm contacts, can be used to operate **automatic control** systems. Naturally the details of the mechanism of control, outside the recording pyrometer, vary according to the conditions of installation, but as examples, gas or air valves may be regulated, electric current or voltage altered to secure any desired conditions.

"High Resistance" Instruments.

Where, as indicated on page 4, the conditions necessitate an instrument of relatively high resistance, the resulting forces available to move the pointer of the indicator or the pen of the recorder are much smaller than in the "Unit" class. By use of the patent **"Resilia" mounting** of the moving system the internal resistance of the instrument can be kept high without introducing objectionable mechanical delicacy or friction errors. The detail construction of this type of instrument is described in the theoretical notes, pages 27 to 39. **"High resistance Resilia"** instruments are available for thermo-couple stems of either "base metal" or of "rare metal".

“ Resilia ” Indicator.

Similarly to the “Unit” class for use in a fixed position a **wall type indicator** is made. It is provided with an “edgewise” scale, see Fig. 3, page 6. The length of the scale is 10 inches (254 mm.). A knife-edge pointer and an anti-parallax mirror allow of very fine readings. For instance on a scale 0°-1100° C. it is quite easy to read to 2° C. with the unaided eye, while, with the **adjustable magnifier,** as shown in Fig. 1 (frontispiece), readings to a single degree may be made even at a considerable distance from the instrument. A full-size reproduction of the 10-in. scale is shown at the top of Fig. 19 on an extending sheet at the end of the book. The **wall type “ Resilia ” indicator** is provided usually with two scales, one in degrees Centigrade or Fahrenheit and the other in millivolts ; it also has an **adjustable red index** which may be set to any desired temperature. Although this is an instrument of accuracy and sensibility sufficient for laboratory or research work, it is, at the same time, simple and robust enough for ordinary industrial use.

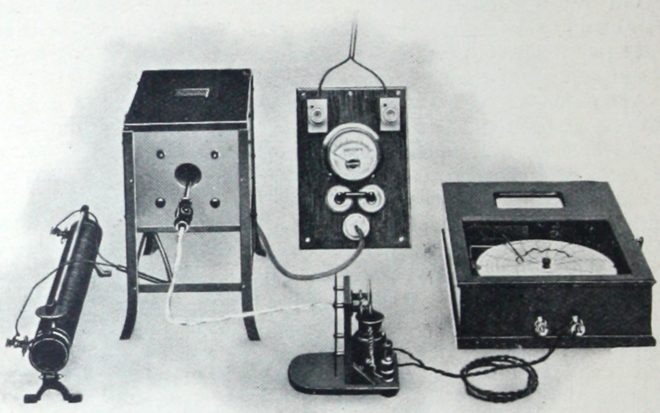

Fig. 11

Laboratory Type Pyrometer, with Horizontal “Resilia” Patent Recorder and Cold Junction Stand.

For portable use, in the “high resistance” class, the **“ Resilia ”** is enclosed in a polished hardwood case (see Fig. 9, page 12), the length of the scale being 7 inches (178 mm.). A full-size reproduction of the 7-inch scale is shown in Fig. 19 on an extending sheet at the end of the book. It is arranged for use with the scale approximately horizontal, though accurate levelling is not necessary, nor is it necessary to lock the coil when moving the instrument, it is only advisable to short circuit the instrument by connecting the two terminals together if it is to be carried or transmitted over any long distance. This instrument is supplied with a knife-edge pointer, and may also be supplied with a millivolt scale and anti-parallax mirror.

"Resilia" Recorder.

The mechanism in this type is similar to that described for the **"Unit"** class on pages 13 to 15, except that the instrument is used horizontal (see Fig. 11, page 16). It should be noted that, although of sensitivity comparable with laboratory instruments, there is **no suspension wire to break,** the coil being carried on **double pivots.**

Fig. 12

Wall-Type Indicator, "Unit" Class, with Open Type Switchboard and Dust-proof Cover.

Cold Junction Compensation.

The method of setting the pointer or pen to the cold junction temperature is briefly but clearly dealt with in the instructions sent out with every instrument; the theoretical notes, pages 27 to 39, also deal with this matter. In those cases where, with a wall type indicator or a recorder of the **"Resilia"** type, the compensating extension is carried right to the indicator or recorder, the instrument can be fitted with an **automatic cold junction compensation** whereby the position of the pointer or pen, when disconnected from the thermo-couple, is automatically kept to the actual cold junction temperature as this changes with change in the surrounding air temperature. This device is particularly convenient in industrial work where skilled supervision is not easily arranged.

Switch.

In many cases it is desirable to read the temperature of several stations (positions where thermo-couple stems are installed) upon one indicator in succession by the use of hand-operated switches. Similarly it may be desired to arrange one recorder so that it may be connected at will to any one of several stations. Two types of switches are made, **"open"** and **"enclosed".** Both types are "double-pole"—that is to say, the make and break of the switch closes and opens the electric circuit at two points, making a complete disconnection between the indicator and the thermo-couple stem when the switch is open. This matter is very important, but is sometimes overlooked. The thermo-couple stem may be so constructed that there is an "earth" or connection to the outer casing or housing or, on the other hand, there may be an accidental "earth" connection. If a "single-pole" switch is used it is quite possible for appreciable errors to occur due to "earth" connections between one thermo-couple stem and another, and where there was metallic continuity in the furnace or other apparatus this has actually occurred in practice with "single-pole" switches. By the use of the "double-pole" switch such an error is entirely prevented, therefore the slight extra cost on the switch is amply justified. In this connection the same chance of error may occur through an attempt to economise on the cost of the cable by using a "common return"; such economy may be dearly bought at the expense of accuracy.

The **"open-type" switch,** shown in Fig. 12, page 17, has all the contacts clearly visible on the face; they can therefore be easily examined and cleaned. The construction gives a firm and reliable contact; the insulation is porcelain. The connections to the circuit are all on the back and are adapted for soldered joints. In the **"Unit"** class of outfit these connections are usually already made when the outfit is sent out. In ordinary industrial work the "open-type" switch is to be preferred; it is cheaper than the "enclosed" switch, particularly on a small number of stations, and it may be protected from dust by enclosing it, with the indicator, in a glass-front dust-proof cover, as shown in Fig. 12, page 17. This type of switch is made for two, four or any even number of stations up to ten, in standard form, or specially up to any larger number, and is normally supplied for the **"Unit"** class outfits. Fig. 17, on an extending sheet at the end of the book illustrates the application of this type of switch.

For those cases where the atmosphere is particularly likely to corrode the switch contacts, the "enclosed" type is used. This is also a "double-pole" switch and is made for twelve stations. It is practically hermetically sealed and therefore well protected against corrosive fumes, yet, owing to its special design, it can be easily dismounted for cleaning and examination when necessary. The "enclosed" switch is usually supplied with the "high resistance Resilia" outfits, an example of this, with **metal base** and **adjustable lamp bracket,** is shown in Fig. 1 (frontispiece) and also diagrammatically in Fig. 18 at the end of the book.

Temperature Ranges.

Instruments are supplied calibrated in Centigrade or in Fahrenheit degrees. Centigrade instruments are usually in stock, and the general tendency now is to adopt the Centigrade scale, The standard ranges are given in the table below :—

"Base Metals", "Unit" or "High Resistance" Classes.

Centigrade.	*Fahrenheit.*
*0° to 400°	*0° to 750°
0° to 650°	0° to 1200°
0° to 1050°	0° to 1900°
0° to 1300°	0° to 2400°

"Rare Metals", "High Resistance" Class for Platinum *v.* Platinum-Rhodium.

Centigrade.	*Fahrenheit.*
0° to 1100°	0° to 2000°
0° to 1400°	0° to 2560°

* In "Unit" class indicators the scale may have **both** of these ranges on the same scale.

These ranges have been specially designed with a view to convenience in the majority of industrial applications of pyrometers, and they will be found to cover conveniently practically any application to which a thermo-couple or stem pyrometer can be applied industrially. It will be seen that the lowest standard range is 0° to 400° C. which will allow of reading with ease to 5° C. or with care to 2° C. In industrial work this is, of course, quite sufficiently close. The highest temperature provided in the standard ranges above is 1300° C. for "base metals" and 1400° C. for "rare metals". See theoretical notes, pages 27 to 39.

Examples of Application.

Diagrams Figs. 17 and 18 at end of book.

To illustrate the use of our standard apparatus in some of the more usual applications to industrial practice, the examples detailed below are chosen. The drawings are on an extending sheet at the end of the book; they are diagrammatic and not to scale. The more usual combinations of stems, accessories and indicators are illustrated, but it will be understood that any desired combination may be made to suit the particular case, provided the general rules as to working range and maximum temperatures are followed. To illustrate the use of a switchboard several stations are shown connected to one indicator—of course, in actual practice the switchboard method is only convenient where the different stations employ stems of similar type and range. In Fig. 17 the wall type **"unit"** indicator is shown with the open-type switch, while Fig. 18 shows the wall type "Resilia" high resistance indicator with the enclosed switch. Advice is freely at the service of inquirers, who should give the information asked for on page 26. In choosing the range of an instrument, to secure the most open scale, it is desirable to select that range which will allow the majority of the work of the instrument being near its maximum—say, between 50% and 90% of the scale range. This is not a fixed rule, but gives a useful guide in selecting the range for a pyrometer.

Station 1, Fig. 17.—For superheated or saturated steam, compressed air, exhaust or other gases, with wall type **"unit"** indicator for fixed use. Usual ranges 0°—400° C. and 0°—750° F. No harm results if, for a short period, the stem should be overheated to 500° C. (932° F.).

The stem—for example, tube type **520.1½**, total length 18 inches (457 mm.)—may be supplied bent as shown at **L,** if desired for convenience in installing. Depth of insertion **a,** usually 6 inches (152 mm.), but must be at least 3 inches (76 mm.). If the pipe is too small in diameter for 3 inches insertion, the stem can usually

be inserted axially on an elbow or T. **d** is **a** plus 2 inches (51 mm.); **f** usually **a** plus 4¼ inches (108 mm.), but may be made to requirements; **h** is the remainder of the length of the stem. The stem is attached to the pipe line, superheater header or other vessel by means of the union **U5,** ¾-inch Whitworth pipe thread (26 × 1.8 mm.). Connection to the circuit is by the connector **C6** and compensating flexible extension **E1,** in flexible metallic tubing **Z.** The diagram shows a wall type indicator, with terminal box **t.** With this arrangement the cable is inserted through a stuffing box and attached to bolted terminals in the terminal box. The indicator is fitted with a wide flange. If this arrangement is not needed, the cable may be sent out attached directly to the indicator, the only break in the circuit then being at the connector **C6.** If it is essential to withdraw the stem without opening the pipe or other vessel to the air, a pocket is supplied in place of the union, but as the cable can be detached at the head of the stem by means of the connector **C6,** it is preferable to have the direct insertion as illustrated, thus securing maximum speed and accuracy.

Station 2, Fig. 17.—For tar product stills, closed vats containing oil, varnish, bitumen or other similar substances. Usual ranges 0°—400° C. and 0°—750° F.

The stem—for example, tube type **700.3,** length 36 inches (914 mm.), diameter ⅝-inch (16 mm.)—may be supplied bent as shown at **L,** if desired for convenience in installing. The stem is fitted with a collar for the union **U3.** Where the stem is inserted into the vessel it is protected from the chemical activities of the liquids or gases therein by the sheath **P25,** 1½-inch Whitworth pipe thread (48 × 2.3 mm.). **a** is usually 9 inches (228 mm.), but can be supplied up to 38 inches (965 mm.), with corresponding increase in the length of the stem. The stem is attached to the sheath by the union **U3,** allowing easy renewal either of the stem or sheath. **f** and **h** usually each 18 inches (457 mm.). Connection to the circuit is by the connector **C1,** compensating extension **E** and cable. May be used singly with an indicator or recorder; or, to serve several stations, with a switchboard as shown.

Station 3, Fig. 17.—For flues, gas ducts, core ovens, enamelling ovens, glass annealing lehrs, and high temperature bake ovens. Usual ranges 0°—400° C. and 0°—750° F.; 0°—650° C. or 0°—1200° F.

The stem—for example, tube type **700.3,** length 36 inches (914 mm.), diameter ⅝-inch (16 mm.)—is shown inserted through the crown of the flue or other vessel. It is held in position by the flange **K3,** allowing variable depth of insertion. The **K3** flange, outside diameter about 4¾ inches (120 mm.), has a set screw clamping on the stem. **a** not less than 5 inches (127 mm.), **d** as required by **a, h** not less than 12 inches (305 mm.). Connection to the circuit is by the connector **C1,** compensating extension **E** and cable. May be used singly with an indicator or a recorder; or, to serve several stations, with a switchboard as shown.

Station 4, Fig. 17.—For oil tempering baths, open varnish vats, baths of low melting salt or white metal. Usual ranges 0°—650° C. or 0°—1200° F.

The stem—for example, tube type **700.3,** length 36 inches (914 mm.), diameter ⅝-inch (16 mm.)—may be supplied bent as shown at **L** to keep it out of the way of the work and to keep the connector **C1** cool. Shown attached to side of bath by clamp hook **J3,** diameter of bolt hole, ⅜-inch (10 mm.). **J3** clamps

on stem allowing variable depth of insertion. **a** not less than 3 inches (76 mm.), **d** as required by **a, f** and **h** usually each 18 inches (457 mm.). Connection to the circuit is by the connector **C1**, compensating extension **E** and cable. May be used singly with an indicator or recorder; or, to serve several stations, with a switchboard as shown.

Station 5, Fig. 17.—For hot air main or down-comer of blast furnace, ducts from large gas producers, carburettors or superheaters of water gas plants. Usual ranges 0°—650° C., 0°—1200° F., 0°—1050° C. or 0°—1900° F.

The stem—for example, tube type **700.3** for the lower ranges, or **1100.3** for the higher ranges, length 36 inches (914 mm.), diameter ⅝-inch (16 mm.)—may be supplied bent as shown at **L.** Shown with steel protecting sheath **M,** diameter $1\frac{1}{16}$ inch (27 mm.), attached to side of vessel by bushing **N,** 1-inch Whitworth pipe thread (33 ×2.3 mm.). The stem is attached to the sheath by a collar and **U3** union. **a** not less than 3 inches (76 mm.), **d** as required by **a, f** and **h** each 18 inches (457 mm.). For exposed positions the weatherhood **V1** protects the head of the stem and the connector. Connection to the circuit is by connector, compensating extension **E** and cable. May be used singly with an indicator or recorder; or, to serve several stations, with a switchboard as shown.

Station 6, Fig. 17.—For baths of lead, aluminium and low melting alloys, galvanising, tinning and soldering baths, and for salt baths, up to 900° C. (1652° F.). Usual ranges 0°—650° C., 0°—1200° F., 0°—1050° C. or 0°—1900° F. Also for barium chloride baths with wire type stem and special sheath, usual ranges 0°—1300° C. or 0°—2400° F.

The stem—for example, tube type **700.3** up to 650°C. (1200° F.) or **1100.3** up to 1050° C. (1900° F.), length 36 inches (914 mm.), diameter ⅝-inch (16 mm.)—may be supplied bent as shown at **L,** to keep it out of the way of work and to keep connector **C1** cool. Shown with cast protecting sheath **P30**, outside diameter 1¼ inches (32 mm.). Held for fixed depth of insertion by clamp hook **J3** which also clamps on stem. **J3** is attached to lip of vessel, diameter of bolt hole ⅜-inch (10 mm.). **a** not less than 5 inches (127 mm.), **d** as required by **a, f** and **h** usually each 18 inches (457 mm.). Connection to the circuit is by connector **C1,** compensating extension **E** and cable. May be used singly with an indicator or recorder; or, to serve several stations, with a switchboard as shown.

Station 7, Fig. 17.—For small furnaces, tempering, carburising, hardening and general experimental work. Usual ranges 0°—1050° C. or 0°—1900° F. For high-speed steel, see Station 8, Fig. 18.

The stem—for example, tube type **1100.3,** length 36 inches (914 mm.), diameter ⅝-inch (16 mm.)—may be supplied bent as shown at **L** to prevent inconvenient projection outside the furnace. It is frequently convenient to insert the stem at the back of the furnace fairly high up so that it will not interfere with the use of the furnace floor. Shown with steel protecting sheath **M1,** outside diameter 1⅜ inches (35 mm.), which clamps, by a thumbscrew, on the stem, and is held in position by flange **K1,** outside diameter about 6 inches (152 mm.), allowing variable depth of insertion. **a** not less than 4 inches (102 mm.), **d** as required by **a, f** and **h** usually each 18 inches (457 mm.). Connection to the circuit is

by connector **C1,** compensating extension **E** and cable. May be used singly with an indicator or recorder; or, to serve several stations, with a switchboard as shown.

Station 8, Fig. 18.—For small furnaces for hardening high-speed steel and other special high temperature work.* Usual ranges 0°—1300° C. or 0°—2400° F. This particular arrangement is specially for high temperature work above 850° C. (1562° F.) and is not recommended for low temperature furnaces, on which the arrangement under Station 7 is preferable.

The stem—for example, wire type **1324.1½w,** diameter of wires ⅛-inch (3 mm.), covered with porcelain sleeves—is protected by a compound sheath with a refractory tip **P33,** diameter 1⅛ inches (28 mm.), and steel upper portion **M7,** held together and attached to furnace wall by flange **K1,** outside diameter about 6 inches (152 mm.). The wire type stem is provided with **head C25,** allowing quick renewal of the wires. **a** not less than 3 inches (76 mm.), **d** as required by **a, p** usually 18 inches (457 mm.). Connection to the circuit is by connector **C1,** compensating extension **E** and cable. May be used singly with an indicator or recorder; or, to serve several stations, with a switchboard as shown.

Station 9, Fig. 18.—For furnaces where the conditions require and are suitable for a platinum *v.* platinum-rhodium thermo-couple. Usual ranges 0°—1100° C., 0°—2000° F., 0°—1400° C. or 0°—2560° F.

The stem—for example, **6520.2**, diameter of wires $\frac{1}{50}$th inch (0.5 mm.), with internal insulation—is protected by a compound sheath—for example, **P85.p/k.** This sheath has an upper portion of steel, not actually inserted into the furnace, diameter 1⅜ inches (35 mm.), and for a range of 1100° C. (2000° F.) the refractory tip is of fused silica (quartz); alternatively, for higher temperatures, of special porcelain. **a** not less than 2 inches (51 mm.), **k,** the exposed length of the refractory tip, longer than **a** by an amount sufficient to prevent the upper steel portion projecting in the furnace, usually 2 inches (51 mm.) longer than **a**, **d** as required by **a**, **p** as required to allow projection outside the furnace not less than 6 inches (152 mm.). The sheath is held in position by flange **K1,** outside diameter about 6 inches (152 mm.). The stem is fitted with head **C25,** allowing quick renewal of the wires. Connection to the circuit is by connector **C1,** compensating extention **E5** and cable. May be used with a high resistance "Resilia" indicator or recorder; or, to serve several stations, with a switchboard as shown.

Station 10, Fig. 18.—For large furnaces for tempering, normalising, annealing, carburising, hardening, pre-heating and general manufacturing work. Usual temperatures 0°—1050° C., 0°—1900° F., 0°—1300° C. or 0°—2400° F.

The stem—for example, for the lower ranges, tube type **1100.3,** length 36 inches (914 mm.), diameter ⅝-inch (16 mm.)—is shown with steel protecting sheath **M1,** diameter 1⅜ inches (35 mm.), clamping on stem with thumbscrew, sheath being held by flange **K1,** outside diameter about 6 inches (152 mm.). In the case of the higher ranges, the wire type stem with refractory sheath, would be used as shown in Station 12. **a** not less than 5 inches (127 mm.), **d** as required by **a, h** at least 12 inches (305 mm.), usually balance of stem length 36 inches (914 mm.). Stem and sheath shown installed in a pocket in the side of the furnace, shielding them from the cutting action of the gases and keeping them out

of the way of the work in the furnace, recess **s** $3\frac{1}{2} \times 3\frac{1}{2}$ inches (89×89 mm.). Connection to the circuit is by connector **C1**, compensating extension **E** and cable. May be used singly with an indicator or recorder ; or, to serve several stations, with a switchboard as shown.

Station 11, Fig. 18.—For large furnaces for tempering, normalising, annealing, carburising, hardening, pre-heating and general manufacturing work. Usual ranges 0°—1050° C., 0°—1900° F., or for specially high temperature work, 0°—1300° C. or 0°—2400° F.* This illustrates arrangement where furnace has an outer flue space or fire space which must be crossed by the stem.

The stem for the lower ranges would be the tube type, and steel sheath etc., as described in Station 10, alternatively, for the higher ranges, the wire type stem—for example, **1324.3w**, diameter of wires $\frac{1}{8}$-inch (3 mm.), covered with porcelain sleeves—is protected by compound sheath **P37,** with refractory tip **P35,** arranged for easy renewal without screwed or cemented joints. Diameter of **P35** $1\frac{1}{2}$ inches (40 mm.), diameter of upper metal portion of **P37,** $2\frac{3}{8}$ inches (60 mm.). Sheath is held in position by flange **K2,** outside diameter about 6 inches (152 mm.), the sheath being protected, if it crosses the outer fire space or flue space, by refractory sleeve **P23,** outside size 6 inches (152 mm.) square, length 12 inches (305 mm.), before being fired, sleeve can be sawn easily if required to reduce length. If desired, when the stem and sheath are removed, the opening may be stopped by a plug **P24.** **a** not less than 5 inches (127 mm.), **d** as required by **a, p** usually 36 inches (914 mm.). Stem is provided with head **C25,** allowing quick and easy replacement of stem wires, and also attachment and detachment of the connector **C3.** Connection to the circuit is by connector **C3,** compensating flexible extension in flexible metallic tubing **E1Z,** with a second connector **C3,** for attachment to cold junction box **C18.** This arrangement gives good protection for the compensating extension, which is easily detachable and replaceable ; the cold junction box **C18** secures steady cold junction temperature which is easily read on the attached thermometer. Cable is usually protected in conduit. May be used singly with an indicator or recorder ; or, to serve several stations, with a switchboard as shown.

Station 12, Fig. 18.—For large furnaces for tempering, normalising, annealing, carburising, hardening, pre-heating and general manufacturing work. Usual ranges 0°—1050° C., 0°—1900° F., or for specially high temperature work, 0°—1300° C. or 0°—2400° F.*

The arrangement shows the installation through the roof at an angle crossing the outer fire space or flue space. It is otherwise similar to Station 11, with the exception that connection to the circuit is by connector **C1,** compensating extension **E** and cable. May be used singly with an indicator or recorder ; or, to serve several stations, with a switchboard as shown.

Station 13, Fig. 18.—For pots of molten metal. Usual ranges 0°—1300° C. or 0°—2400° F. The illustration shows two alternative types of stem, described below, either or both of which may be used on the same indicator interchangeably.

For use on all ferrous metals also on non-ferrous metals, while the metal is still in the furnace, or upon large pots out of the furnace where the cooling is not rapid, the compound sheath **P18** is used as shown, with the refractory tip **P15.** The sheath

is provided with a socket **N2,** which has a lug by means of which it may be conveniently rested on the side of the pot or, alternatively, slung from overhead to relieve the user of its weight. For this use the stem—for example, wire type **1324.5w**, length 60 inches (1524 mm.), diameter of wires ⅛-inch (3 mm.)—is protected by porcelain sleeves inside the sheath, and is fitted with head **C25**, allowing quick and easy attachment of renewal wires and also of the connector **C3.** Time for a steady reading from cold about 5 minutes or, when passing from pot to pot, about 2 minutes. **a** not less than 5 inches (127 mm.), **d** usually about 18 inches (457 mm.), **p** usually 60 inches (1524 mm.). Alternatively, for momentary insertion on small pots of non-ferrous metal, out of the furnace, where cooling is rapid, the stem shown on the right is used—for example, **1314.5w,** diameter of wires, ⅛-inch (3 mm.)—protected by fireclay compound, the junction between the two wires being directly inserted in the metal. The non-ferrous metal only alloys the wires away very slowly, and if the junction has been destroyed the metal itself forms a junction, thus the use of the stem may be continued until it is too short for convenience, several readings being obtained per inch of stem used. The stem is fitted with handle **H3** and head **C25,** allowing rapid and easy renewal of wires and attachment of connector **C3. p** usually 60 inches (1524 mm.). Connection to the circuit is by connector **C3,** compensating flexible extension in flexible metallic tubing **E1Z,** attached directly to the portable indicator as shown. May be used alternatively with a wall type indicator.

Station 14, Fig. 18.—For large furnaces for tempering, normalising, annealing, carburising, hardening, pre-heating and general manufacturing work, showing horizontal insertion through side of furnace, if necessary crossing outer fire space or flue space. Usual ranges 0°—1050° C. or 0°—1900° F. or, for specially high temperature work, 0°—1300° C. or 0°—2400° F.*

The stem—for example, for the lower ranges, tube type **1100.3,** length 36 inches (914 mm.), diameter ⅝-inch (16 mm.)—may be supplied bent as shown at **L.** Shown with Hoskins' special alloy sheath **P19,** a length of 12 inches (305 mm.) being of the Hoskins' special alloy, the remainder of the sheath being a lengthening piece of steel. Sheath clamps on stem with thumbscrew and is held in position by flange **K1,** outside diameter about 6 inches (152 mm.). If an outer flue space or fire space is to be crossed where the tube type stem and **P19** sheath are used, the refractory sleeve **P21** is used, outside size 3 inches (76 mm.) square, length 12 inches (305 mm.), before being fired, sleeve can be sawn easily if required to reduce length. If desired, when the stem and sheath are removed, the opening may be stopped by a plug **P22. a** not less than 5 inches (127 mm.), **d** as required by **a, f** and **h** each usually 18 inches (457 mm.). For the higher ranges, the stem, sheath, flange and, if needed, the sleeve are as in Station 11 above. Connection to the circuit is by connector **C3,** compensating flexible extension in flexible metallic tubing **E1Z,** with a second connector **C3** for attachment to cold junction box **C18.** This arrangement gives good protection for the compensating extension, which is easily detachable and replaceable, the cold junction box **C18** secures steady cold junction temperature which is easily read on the attached thermometer. Cable is usually protected in conduit.

This illustration shows a wall type indicator adjacent to the furnace, protected in a hardwood dust-proof cover **D1,** and, at a distance, as for instance in the superintendent's office, a recorder.

The recorder is attached to the plug **C14** by the connector **C3** and flexible cable in flexible metallic tubing. Special switching arrangements can be provided whereby several stems are connected in turn to one indicator near the furnace, by the switch board, another switchboard being fixed adjacent to the recorder, by means of which a record may be made at will from any of the stations without interfering with the use of the indicator.

*For this work the FOSTER FIXED FOCUS PYROMETER is frequently preferable, being very rapid in action and working entirely at a distance, see separate booklet.

Directions for Ordering.

EXPERT ADVICE—the result of many years' experience—is freely at the service of all enquirers. The varied nature of the applications of the FOSTER PRACTICAL PYROMETERS prevents the cataloguing of all the various types made to suit special cases. Proposals and quotations will be submitted on receipt of particulars. Enquiries or orders should give information on the points indicated below :—

1.—What are the processes and types of apparatus for which the pyrometers are wanted ?

2.—Is the furnace, or other containing vessel, at atmospheric pressure ? If not, state the actual maximum pressure or draught.

*3.—What are the highest and lowest temperatures to be measured ? Is the scale to be Centigrade or Fahrenheit ? See list of standard ranges, page 19, and examples in Fig. 19 at end of book.

*4.—State whether it is intended to use a wall type (fixed) or portable indicator, or a recorder. See Figs. 2, 7 and 10. A combined outfit, with wall type indicator and recorder, is often the most useful. See Station 14, Fig. 18, at the end of the book.

5.—What are the dimensions of the stems ? The lettered dimensions in the diagrams Figs. 17 and 18 at the end of the book illustrate the kind of information required. What accessories are required ? See Figs. 17 and 18 for these particulars also. If in doubt send sketches, drawings or blue prints of the apparatus.

6.—What arrangement is to be made for the cold junction ? See pages 10 and 11. Is the usual "Unit" 2-foot extension satisfactory or is it desired to have longer flexible extensions, covered with flexible metallic tubing and employing the cold junction box ; or, alternatively, is it preferred to have a "high resistance" instrument with the extension carried right to the instrument ? See pages 15 to 17.

7.—What will be the average temperature of the cold junction ? If no information is given on this point, it will be assumed at the usual average of 30° C. or 86° F., but the user can alter the setting at will.

*8.—What is the length of cable needed to connect each stem to the indicator, recorder or switchboard ? Allow enough for bends and "up and down" wiring. Are there any long spans or other difficulties in running cables ? Is conduit to be supplied ? See "Examples of Application", pages 19 to 25, and Figs. 17 and 18 at end of book.

The questions marked * must be answered before an outfit can be completed, unless ordered by quoting catalogue numbers. The position chosen for the indicator should not be hotter than 40° C. (104° F.), or for the recorder not over 35° C. (95° F.).

SPARE PARTS.—It is always advisable, particularly on export orders, to order at least one spare stem and sheath of each kind used. This saves delay when renewals are needed. When subsequently ordering parts for instruments already delivered, the type and serial numbers marked on those instruments should be quoted.

Telephone : **Letchworth 26.** *Telegrams :* **"Foster Instruments, Letchworth."**
Code : 5th Edition A.B.C.

THEORETICAL NOTES.

One of the most encouraging advances in the application of pyrometers to industry at the present time is the increasingly intelligent interest taken by the users in the considerations affecting the design and use of pyrometers. It is thought, therefore, that the following theoretical notes, showing the successive reasoning and stages of development leading to the present types of FOSTER PRACTICAL PYROMETERS, will be of general technical interest.

The thermo-couple or thermo-electric pyrometer comprises a junction between two dissimilar metals or alloys, and the measurement of temperature by means of the thermo-couple is made by the electro-motive-force or voltage generated when the junction is heated to a temperature different from the rest of the electric circuit. The history of the discovery of this property of the thermo-couple and its application to temperature measurement is very interesting, but it is not possible, in the scope of these notes, fully to discuss that history.

Thermo-Electric Circuit.

In Fig. 13 are shown six successive developments of the thermo-electric circuit. **A** shows the simplest form of electric circuit in which the two metals are joined together at each end, one junction being heated to a temperature above that of the other. This junction is, therefore, called the "hot junction", and the other, conversely, the "cold junction". Although a current would flow in the circuit due to the electro-motive-force generated, in the arrangement as shown at **A** there would be no exterior indication of it. It is, therefore, necessary to modify the circuit—for instance, as shown at **B.** In this arrangement the cold ends of the thermo-couple are joined to the two terminals of a galvanometer or millivoltmeter, and are then termed collectively the "cold junction". The millivoltmeter will now give an indication of the passage of a current and a measure of its magnitude. This illustrates the simplest form of indicating thermo-couple circuit.

Assuming that the metals comprising the thermo-couple are suitably chosen, this apparatus might now be calibrated as a pyrometer. With the hot junction and the cold junction at known temperatures, the electro-motive-force generated would have a particular value, and consequently the current flowing in the circuit and through the indicating millivoltmeter would also have a fixed value, provided the electric resistance of the circuit, including the millivoltmeter, remained constant; the deflection of the indicator pointer could, therefore, be made to show directly the temperature of the hot junction under those circumstances.

In practice it is not possible, in an industrial pyrometer, to realise the conditions indicated at **B.** The hot junction being at a relatively high temperature, the thermo-couple itself, at any rate over part of its length, would also be raised in temperature, and the indicating millivoltmeter may be at a different temperature from that at which the original experiment of calibration was made. These changes in temperature of the thermo-couple and the indicating millivoltmeter will cause changes in their electric resistance, and consequently the indicator will no longer show directly the temperature of the hot junction. For these reasons it is usually necessary to insert into the thermo-couple circuit an additional "ballast" resistance. This ballast resistance is made of material which in itself does not change in resistance with change in temperature, and it is made so large, in comparison with the other resistances of the circuit, that any change in those other resistances, due to change in their temperature, is relatively small and without appreciable effect upon the indicator reading. This modification is shown at **C.**

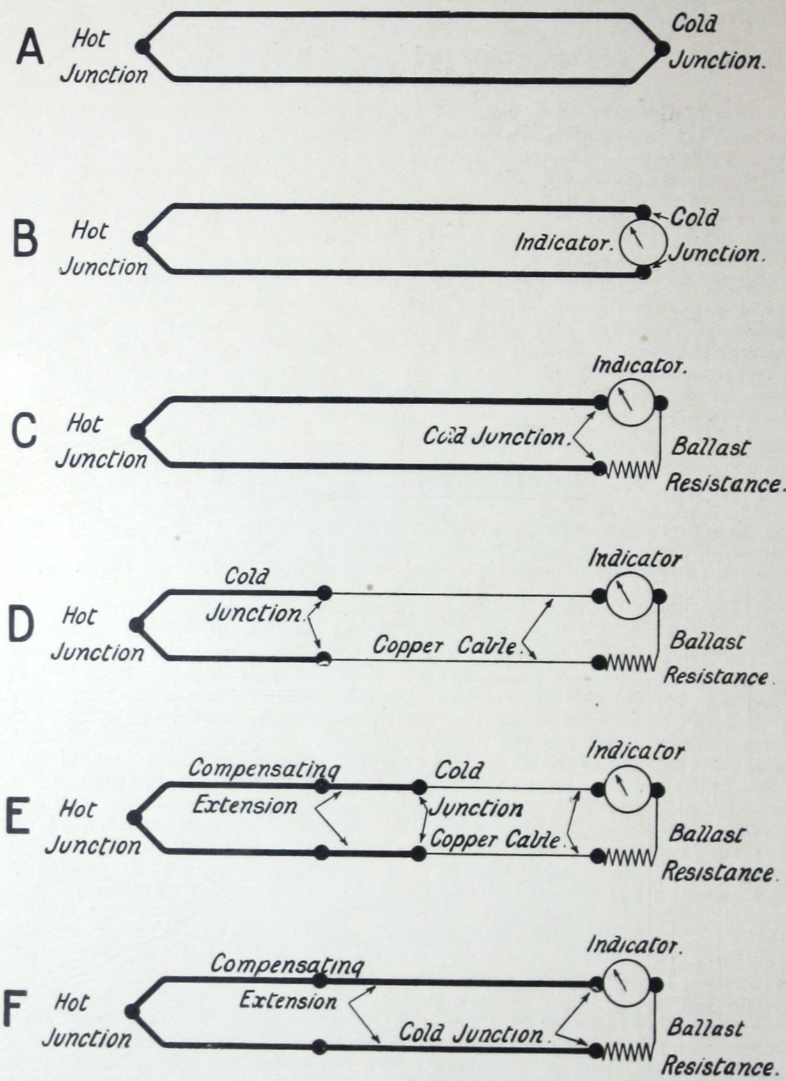

Fig. 13.

Developments of the Thermo-Electric Circuit.

Unless the distance, between the hot junction whose temperature is to be measured and the indicator which makes the measurement, is very short, the arrangement at **C** is not convenient, and if renewal of the thermo-couple should be necessary, the whole length from the hot junction to the cold junction would have to be renewed. It is therefore convenient, usually, to use a thermo-couple of relatively short length and to connect its cold junction to the indicator by twin copper cable, in which case the ballast resistance is usually included inside the indicator case. The electrical resistance of the copper cable will change if its temperature changes, and this makes it therefore necessary for the ballast resistance to be still larger, in order that it may obliterate practically the effect of change in resistance of the rest of the circuit.

It was stated above, as a condition for the indicator to be calibrated directly in temperature, that the hot junction and the cold junction must be at known temperatures; if the hot junction remains at a steady high temperature, but the relatively low temperature of the cold junction should change, the reading of the indicator will change, because the current it is measuring depends upon the *difference* in temperature between the hot junction and the cold junction. It is therefore necessary, if the indicator is to be direct reading in temperature, that the cold junction should be maintained at the temperature which existed when the instrument was calibrated, otherwise a correction would be necessary to the reading. It has been customary, until recently, to maintain the cold junction at the temperature of melting ice (0° C., 32° F.) during the calibration, and if in use the cold junction were not at 0° C. (32° F.) a correction was made arithmetically to the observed reading on the indicator. Unless the thermo-couple is such that it gives absolutely equal additions of electro-motive-force for equal additions of temperature to the hot junction—that is to say, unless the thermo-couple has a "straight-line law"—this arithmetical correction which it would be necessary to apply to the observed reading would be an amount varying not only with the actual cold junction temperature but with the observed reading of the hot junction temperature. This is cumbersome, and has been superseded by the following method.

As already explained, the current flowing in the circuit, and producing the temperature reading on the indicator, will depend upon the difference between the temperature of the hot junction and that of the cold junction of the thermo-couple; in a thermo-couple of suitable metals or alloys, the greater this difference of temperature, the greater the current. The scale of the indicator may be made "direct reading" as follows:—

The cold junction is maintained at a steady temperature, for instance 0° C. (32° F.) and, before connecting the thermo-couple to the indicator, the indicator pointer is at the zero or lowest position on the scale and that position is marked 0° C. The hot junction is then heated to a steady known temperature—say, 100° C.—the scale then being marked "100" at the position taken up by the pointer; similarly, the hot junction may be heated to 200° C. and the scale marked correspondingly, and this process may be carried on up to the maximum reading of the scale, maintaining the cold junction all the time at 0° C. (it is sometimes convenient to leave out the "0's", specifying the scale as "Hundreds Centigrade" and figure the calibration points 1, 2, 3 and so on). By this method of calibration, each successive step in the scale has been divided according to the current proportional to that difference of temperature—for instance, the width of scale between "100" and "200" is proportional to the current which would flow if the cold junction were at 100° C. and the hot junction at 200° C., and so on all up the scale. Following the explanation above, it will be evident that if the hot junction were maintained at, say 300° C. and the cold junction, which had been previously at 0° C., were allowed to heat up to 10° C., there would be less current flowing because there would be less difference in temperature between the hot junction and the cold junction, although the hot junction has remained at a steady temperature. This difference in current would be represented, on the scale, by the distance from "0" to "10", so that, if we disconnect the thermo-couple from the indicator and set the pointer at 10° C., on reconnecting, the indicator will read correctly the temperature of the hot junction because we have added, on the scale, the amount which we lost by the rise in temperature of the cold junction from 0° to 10°.

Similar results will follow for any particular temperatures of the cold and hot junctions; provided the pointer is set to the actual cold junction temperature before the indicator is connected to the thermo-couple, the pointer will then always point to the true temperature of the hot junction.

This method of setting the pointer is at once simpler and less liable to error than the older method of setting the pointer at 0° C. (32° F.) and making an arithmetical correction to the observed reading.

The thermo-couple now being supposed relatively short, as in condition **D**, it is possible that if the hot junction is inserted into a furnace the cold junction will be liable to change its temperature due to radiation from the furnace and thus involve re-setting the pointer of the indicator at inconveniently short periods. To get over this difficulty, the arrangement as shown at **E** may be adopted. The thermo-couple is joined at its outer end to a **compensating extension**—that is, to two metals or alloys which are thermo-electrically interchangeable with the thermo-couple—so that, in effect, the cold junction is removed to such a distance from the furnace that its temperature will remain conveniently steady. In this form, as at **E**, a practical industrial thermo-couple pyrometer is made.

If the conditions are suitable, the compensating extension may be prolonged right up to the indicator as shown at **F.** It is then easy for the user to measure the actual temperature of the cold junction at the indicator and, the indicator being disconnected, to set the pointer to correspond with that temperature. A further modification is to incorporate in the indicator some form of automatic apparatus whereby the position of the pointer is changed in accordance with the change of temperature of the indicator, thus making the whole apparatus purely automatic. Various experimenters have proposed and used modifications of this **" automatic cold junction setting ",** and a practical realisation is employed with the **" Resilia "** indicators of the wall type.

The part of the millivoltmeter mechanism which controls the " zero " position of the pointer (when not connected to the thermo-couple) occupies a fixed position in the normal instrument ; in the **" Resilia "** patent, with the automatic cold junction setting, this part is moved automatically so that, as the cold junction temperature increases, the " zero " position of the pointer increases to the same extent, thus carrying out, automatically, the operation of pointer setting referred to above, but doing it without any disconnecting from the thermo-couple, or other attention from the operator. This arrangement, operating as it does by the indicator temperature, can only be used in those cases where the cold junction is brought actually to the indicator.

Choice of Alloys.

Metals and alloys available for the construction of thermo-couple pyrometers fall into two classes, namely, those constructed of " rare " or " noble " metals—for instance, platinum, rhodium, iridium, etc.—and those employing " base " or cheaper metals—for instance, iron, copper, nickel, chromium, etc. These terms should only be considered in relation to thermo-couples in the above sense, it should not be inferred that the behaviour of the one class is " noble " or of the other class " base ", in fact, under some conditions, the reverse is frequently true. The most important distinctions between the two classes are shown below.

The primary consideration which determines the suitability of alloys for use as thermo-couple pyrometers is the maximum temperature which is to be measured. High temperature is applied to the material in manufacture to produce some change in the material, but the same high temperature should not produce any change in the apparatus used to measure the temperature. This is an ideal which is easily attainable when the temperatures are low, say below 500° C. (932° F.), but it becomes increasingly difficult as this temperature is exceeded.

In considering the possible effects of high temperatures upon the thermo-couple alloys, their melting point is the first quality which comes in view; it is obvious that the melting point of the thermo-couple must be above the maximum temperature to be measured. Unfortunately, in many metals which have a very high melting point, there are other defects which set a limit to the maximum temperature to which they can be heated. In some cases oxidation is the most serious cause of destruction, while in other cases contamination by gases and metal vapours is the more serious consideration.

Where very high temperatures have to be measured and where the conditions of use indicate the thermo-couple as the desirable type of pyrometer, platinum and its alloys frequently provide the best type of thermo-couple. The two best known rare-metal thermo-couples employ one wire of pure platinum, the other wire being 90 % platinum with 10 % of rhodium or iridium

respectively. These materials do not oxidise seriously, even at temperatures approaching their melting points. Unfortunately, when used at temperatures above 1000° C. (1832° F.) the contaminating effects of reducing gases and metal vapours tend to destroy the mechanical strength and to alter the electrical calibration. When suitable protection can be given and conditions otherwise favourable can be secured, as, for instance, in many laboratory experiments, it is possible to use the platinum *v.* platinum-rhodium thermo-couple up to temperatures as high as 1600° C. (2912° F.).

With the platinum *v.* platinum-iridium couple volatilisation of the iridium, and contamination of the pure platinum, prevent satisfactory use of this thermo-couple at temperatures over 1000° C. (1832° F.).

These rare metals being expensive, it follows that they must be in the form of thin wires, usually of diameter 0.5 mm. (1/50th inch), they are therefore mechanically delicate. A second consequence of the thin wires is that their electrical resistance is very high, and therefore the change in resistance, when the thermo-couple wires are heated by being inserted into the furnace, will also be large. The electro-motive-force is very small—for instance, a thermo-couple having one wire of platinum and the other wire of 90% platinum and 10% rhodium develops an electro-motive-force about one hundredth of a volt (10 millivolts) when the temperature is about 1000° C. (1832° F.) and the cold junction at 0° C. (32° F.).

As explained above, it is necessary to introduce into the circuit an additional or "ballast" resistance; this is usually incorporated in the indicator or recorder. When the thermo-couple is inserted into the furnace there will be fractional increase in its resistance, depending upon its resistance when cold and upon the temperature-resistance co-efficient of the materials in the thermo-couple. With the platinum *v.* platinum-rhodium thermo-couple, owing to the expensive nature of the material and the consequently small diameter of the wires, the resistance when cold is high and, the temperature-resistance co-efficient being large, the further increase in resistance, when it is heated in the furnace, is a relatively large amount. It is obvious, therefore, that the ballast resistance in the circuit must also be very large in order that these changes in resistance shall not have material effect. Any considerable fractional change in the resistance of the circuit would make a proportionate change in the current flowing for any given temperature difference between the hot and cold junctions of the thermo-couple.

It results, therefore, that the whole electrical circuit in connection with the platinum *v.* platinum-rhodium thermo-couple must be of high resistance, usually more than 100 ohms; therefore it will be clear that the current flowing in the circuit is extremely small. The force tending to move the indicator pointer is therefore also extremely small, because it depends upon the current flowing in the circuit. In the case mentioned above, for a temperature of 1000° C. (1832° F.), an electro-motive-force of 10 millivolts acting in a circuit of 100 ohms results that the current flowing in the circuit is only one ten-thousandth of an ampere (0.1 milliampere). This point is further discussed below.

The current being so extremely small complicates the problem of making a robust indicating millivoltmeter for use with rare metal thermo-couples. In the past the instrument maker, desiring to have as large a force as possible to move the pointer of the indicator, scaled the instrument for the highest temperature at which it could be used safely under favourable conditions—that is to say, up to 1600° C. (2912° F.). Ignorance of the many difficulties in measuring such high temperatures by means of thermo-couples under industrial circumstances resulted in extravagant claims by the makers and much disappointment by users. Extended experience has shown that, in the majority of circumstances met under industrial conditions, such high temperature for the maximum of the range is misleading and unduly cramps that portion of the scale which can be usefully employed. It is, nevertheless, persisted in by some makers because it tends to disguise lack of sensibility in the indicating instrument.

If the thermo-couple wires are exposed directly to furnace gases, destruction by contamination will take place very rapidly at any temperature exceeding 1000° C. (1832 °F.), and some form of protection must be adopted. The choice of the protecting sheath is a fundamental consideration in thermo-couple pyrometry. A very wide search has been made amongst the possible materials which can be used at high temperatures to protect rare metal thermo-couples from injurious effects of furnace gases, and the choice is narrowed down to two alternatives, a fine grade of porcelain, externally glazed to render it gas-tight, or fused silica (quartz). Glazed porcelain will

protect the thermo-couple wires from furnace gases for a considerable time up to about 1300° C. (2372° F.), but it is essential that the heating and cooling of the porcelain should be slow and uniform, otherwise it is liable to crack. Fused silica withstands sudden changes of temperature better but, like porcelain, it is also fragile. Silica has, further, a tendency to devitrify when used for long periods over 1100° C. (2012° F.). There are no other known substances really suitable for protecting rare metal thermo-couples; of course, metallic sheaths are out of the question because, at high temperatures, they themselves would give off metal vapours resulting in contamination of the wires.

Bearing in mind the conditions of industrial pyrometry it is clear, therefore, that the limiting temperature is that of the sheath and not the melting point of the wires; in practice it is usual in modern designs to limit the maximum temperature for a porcelain sheath to 1400° C. (2552° F.), or for a silica sheath to 1100° C. (2012° F.). In an attempt to compensate for the mechanical fragility of porcelain or silica the expedient of an external wrapping of asbestos and then an outer metal sheath is sometimes adopted, but in practice this makes the indication of the pyrometer very slow and it combines the weight of metal with the fragility of quartz or porcelain and is, in any case, limited to the temperature at which the metal sheath will not oxidise rapidly, say below 1000° C. (1832° F.). In some cases this cumbersome double sheath makes the pyrometer so slow as to justify the criticism levelled at it by one highly expert user, that the pyrometer was "measuring the temperature of last week".

Having recognised that, under industrial circumstances, thermo-couple pyrometry is limited to a maximum temperature of 1400° C. and for continuous work not even as high as that, it is natural to examine the base metal alloys as possible alternatives. Where the temperatures exceed 1000° C. (1832° F.) the choice of base metal thermo-couples is very limited, that due to Hoskins being the most satisfactory type. In this **Hoskins' thermo-couple** one wire is an alloy of nickel and chromium while the other wire is nearly all pure nickel and in each of the wires great care is taken to eliminate iron and other impurities. This thermo-couple has a melting point above 1400° C. (2552° F.), the wires oxidise very slowly and are practically uninfluenced by metal vapours. They should, however, be protected from reducing gases, particularly in the region of 800° C. (1472° F.). This precaution is not of great practical importance because, where the temperatures are usually below 900° C. (1652° F.), other types of base metal thermo-couples are available—for instance, the tube type, described also in the body of the catalogue.

Owing to the relatively low cost of the base metals the cross section of the thermo-couple can be made very much larger—for instance, in the standard wire type thermo-couples the diameter of the wire is 3 mm. and in the tube type the cross-section is even larger, therefore the mechanical strength is much greater than with the rare metals. Further, the electrical resistance is low and, fortunately, the increase of resistance when the thermo-couple is heated in the furnace is also very low. The electro-motive-force is high, approximately four times as high as in the case of the platinum *v.* platinum-rhodium thermo-couple. It follows that the ballast resistance may be proportionately smaller, and therefore the whole electrical resistance of the circuit relatively low—for instance, 10 ohms—without introducing any appreciable errors due to change in the resistance of the thermo-couple. Contrasting this with the case of the rare metal thermo-couple with a circuit resistance of 100 ohms it will be seen that for the same temperature the current flowing will be about forty times as large with the base metal thermo-couple. The problem of making a robust indicating millivoltmeter then becomes at once simpler and cheaper.

The qualities necessary in the protecting sheath are less exacting than with the rare metal thermo-couple. Something which will prevent rapid air circulation round the thermo-couple wires, and also will prevent direct attack by furnace flames, is sufficient to reduce oxidation and to prolong the life of the thermo-couple. For temperatures below 900° C. (1652° F.) a stout steel sheath is quite suitable, while up to 1050° C. (1922° F.) the sheath may be made of a **nickel chromium alloy** similar to that used in the **Hoskins' thermo-couple,** giving a long life of sheath with good protection of the thermo-couple. Above 1050° C. (1922° F.) it is necessary to use refractory material such as fireclay, but there is not the same need that it should be gas-tight as in the case of the rare metal.

To summarise this section, it may be said broadly that the rare metal

thermo-couple is to be preferred where the temperatures to be measured are very high and where the conditions are suitable for the protection of the relatively fragile porcelain or quartz sheath, and the consequent cost and delicacy are not objectionable ; on the other hand, for those cases where mechanical robustness is of primary importance and where the temperature is not too high, the base metal thermo-couple may be employed with less anxiety as to the care of the instrument and also a lower expense in first cost and upkeep.

Circuit Resistance.

It has already been pointed out above that change in the electrical resistance of the circuit will arise, due to the heating up of the thermo-couple when inserted in the furnace, and it should be noted here that this change will vary with the depth of insertion in the furnace, quite irrespective of the actual temperature measured, and there will be also change in the resistance of the connecting cable and the coil in the indicating millivoltmeter, due to changes in atmospheric temperature. In order that these changes shall not affect the accuracy of the instrument to an objectionable extent, it is necessary to add " ballast " resistance, of material which does not change its resistance with temperature, to such an amount as to reduce the total probable change in circuit resistance to the order of, say, 1 %.

Figures are contrasted below for a typical example of a "rare metal" thermo-couple pyrometer of platinum *v.* platinum-rhodium and a " base metal " outfit of Hoskins' alloys :—

	Rare Metal.	*Base Metal.*
Resistance of thermo-couple stem when cold	2 ohms.	0.1 ohm.
Probable variation of thermo-couple resistance due to insertion to different depths and into furnaces at different temperatures	1 ohm.	0.01 ohm.
Resistance of copper cable	1 ohm.	0.25 ohm.
Resistance of copper coil in indicating millivoltmeter	24 ohms.	2 ohms.
Probable change in resistance of cable and coil due to change in atmospheric temperature	1 ohm.	0.09 ohm.
Therefore probable total change in circuit resistance	2 ohms.	0.1 ohm.
Minimum total resistance by addition of ballast in order that above change in resistance does not exceed 1 % of the total resistance	200 ohms.	10 ohms.
E.M.F. of thermo-couple at 1000° C.	10 millivolts.	40 millivolts.
Current flowing in moving coil of indicating millivoltmeter, generating the operating force, in milli-amperes (thousandths of an ampere)....	$\frac{10}{200}=0.05$ m.a.	$\frac{40}{10}=4$ m.a.

It will be seen, therefore, that the current flowing and generating the force to move the indicator pointer is eighty times as large with the " base metal " as it is with the " rare metal ". In practice, owing to other detail considerations of design (number of turns in the moving coil, etc.), the actual deflecting force is thirty to forty times as large in the " base metal ".

It will be noted, in the above typical figures, that the cable was chosen of lower resistance in the case of the base metal, this is because it is worth while spending a little more on copper in order to achieve the great increase in mechanical robustness. This matter of copper resistance, though only concerning a small fraction of the total cost of the pyrometer installation, is really fundamental to the choice of the design. Very often mechanical strength, to resist breakage in handling under industrial circumstances, requires the use of a cable of fairly heavy section, and the desired low resistance is thereby already achieved ; but in any case the economy in cable, if thin wires were used with their consequent high resistance, is dearly purchased under industrial circumstances if the indicating instrument has to be made less robust. Such a practice dates back to the early days of industrial pyrometry when the user was supplied by the maker with a length of platinum and platinum-rhodium wires, fused together, some fireclay beads

for insulation, a porcelain tube for a sheath and a suspended coil indicating millivoltmeter calibrated in millivolts and temperature without relation to the circuit conditions, and he was then expected to "work out his own salvation" with any kind of copper wire which he had handy, frequently very flimsy material. We should not allow the design of our pyrometer installation to be governed by "a hank of bell wire". The modern method is to design the pyrometer installation as a whole, taking into account all the factors and parts necessary to its operation and making sure that all the various fittings are suitably strong for the industrial circumstances.

It is clear that, for the rare metal thermo-couple, owing to its large change in resistance, it is essential that the circuit resistance shall be high, low resistance is quite out of the question. It is also clear that in cases where long cables of high resistance are unavoidable, or where the lengths of different cables in one installation vary very largely, the indicating instrument again may be of high resistance, but in all other cases where the pyrometer can be made up as a unit with short cables of known and low resistances, full advantage of the robustness of the base metal thermo-couple can be reaped in making the indicating instrument also very robust and, at the same time, of low cost.

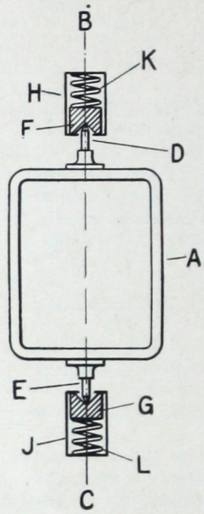

Fig. 14.

**Millivoltmeter Coil Mounting
Typical Spring Jewels.**

Millivoltmeter Design.

Practically every pyrometer millivoltmeter is of the D'Arsonval type, that is, comprising a coil of insulated wire carrying the current to be measured and rotating in the field of a permanent magnet. The passage of the current through the coil produces a tendency to rotate in the magnetic field in the same way as the passage of the current through an electric motor, but the tendency to rotate is restrained by spring control so that the angle of rotation is a measure of the current flowing. The pointer of the indicator or the pen of the recorder, being attached to the moving coil, makes the instrument direct reading.

In the earlier designs of pyrometer millivoltmeters the moving coil was always suspended by a fine wire or strip, the twisting of the wire or strip furnishing the controlling forces. This construction avoids trouble with friction and enables a relatively wide angle of deflection to be produced by a very small current. A suspended coil instrument of this kind has, however, the industrial disadvantages that it must be mounted upon a firm support free from vibration and must be carefully levelled before use. If

the instrument is to be carried about, the coil must always be locked to remove the strain from the suspension before the instrument is moved, it is therefore not a type suitable for general industrial work ; it is, however, used even to-day in some cases where very high resistance or very high sensibility is required.

Subsequent improvements have resulted in mounting the moving coil upon one or two pointed pivots working in jewels. Accurate levelling is not necessary with this improvement, vibration is less likely to upset the reading immediately, but there is the danger that vibration may ultimately damage the pivots, resulting in a "sticky" movement ; it is obviously little use having an instrument whose calibration is accurate say to 5° where there may be a friction error as large as 10°. The forces available to over-

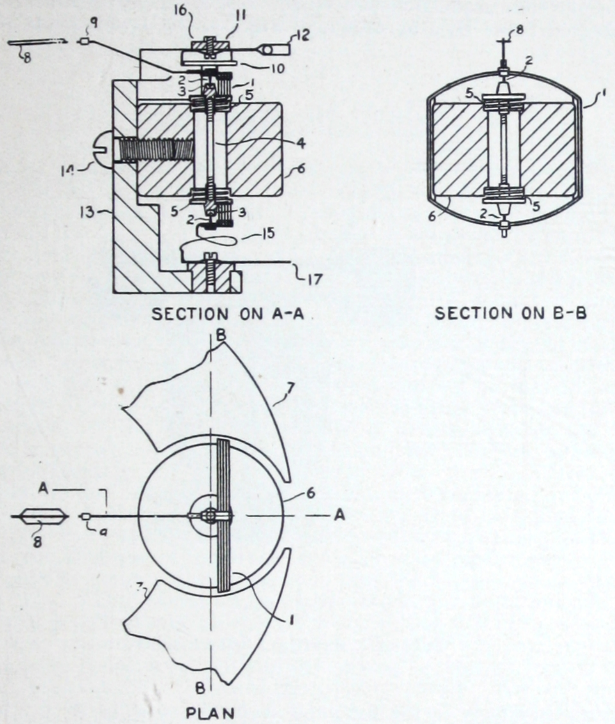

Fig. 15.

Diagram of Patent "Resilia" Movement.

come friction in a pivoted instrument of this kind are even smaller than apparent at first glance. Consider an instrument which is, for the moment, at a steady reading at 900° C. (1652° F.) and then suppose that the temperature has risen to 910° C. (1670° F.). The deflecting force due to the current consequent upon the temperature of 900° C. (1652° F.) is already balanced by the spring control so that the only force available to overcome the static friction of the pivots in their jewels is that due to the extra current generated from 900° C. (1652° F.) to 910° C. (1670° F.). In a high resistance instrument this force available to overcome pivot friction is possibly as small as one-tenth of a dyne-centimetre. It is therefore evident that the designer in making a high resistance pyrometer millivoltmeter with double pivots is tackling a very difficult problem. It is not only essential that the friction errors shall be small when the instrument is made and calibrated, but also that the ordinary vibration of industrial use shall not damage the pivots, as obviously the excessively small forces indicated above would not produce any movement upon an instrument with damaged pivots or jewels, the instrument would tend to become "sticky" and therefore inaccurate.

Various methods have been proposed and tried in order to shield the pivots and jewels from damage due to vibration. In Fig. 14 the component parts of the instrument are shown diagrammatically, **A** is the moving coil turning about the axis **B C.** The coil is carried upon pivots **D, E** working in jewels **F, G.** Considering vertical vibration in the direction **B C,** the point of the pivot may be flattened against the bottom of the jewel, but in the case of transverse vibration, which is more dangerous, the point of the pivot may be broken off by coming sideways against the inclined face of the jewel. Reduction of the weight of the moving coil has obvious advantages, seeing that it decreases the load upon the pivots and the weight tending to break them off in vibration, but it has the disadvantage that it reduces the number of turns of wire in the coil carrying the current to be measured and thereby reduces the turning force in the same proportion. In some patterns used an improvement was made by mounting the jewel in shouldered tubes **H, J** as shown in Fig. 14, the jewels being pressed up

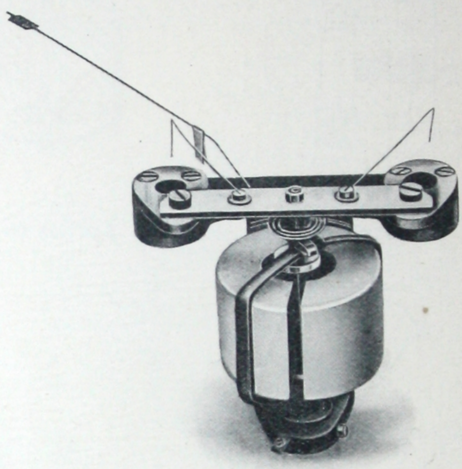

Fig. 16.

Patent "Resilia" Movement.

against the shoulders of the tubes by very light springs **K, L.** Again considering vertical vibration, a downward movement of the coil **A** would press the pivot **E** against the jewel **G** and compress the spring **L,** thus preventing a severe blow between **E** and **G.** Unfortunately, however, the pivot **D** would then move relatively far away from the jewel **F** and, on the rebound, **D** would strike **F** with considerable force. If the jewels were mounted without the shoulders on the tubes they would then press continuously against the ends of the pivots and thus actually cause more friction. A further disadvantage of this construction is that there is no protection against damage due to transverse vibration.

The **"Resilia"** patent design is arranged so that it is impossible for the pivot and jewel to be separated, and therefore they cannot strike each other in vibration. In Fig. 15 this construction is indicated diagrammatically. A magnetic field is established between the pole pieces of the magnet **7** and the cylindrical iron core **6**. The coil **1**, carrying the current by means of which the measurement is made, swings in the space between **6** and **7**, turning about an axis **4**. The coil carries inturned pivots **2**, having their bearings in the conical jewels **3**. These jewels are mounted upon a staff **4**, which itself is very light and which is held in position relatively to the core **6** by the light springs **5**. Any jolt of the instrument, therefore, will move the whole system of coil, pivots, jewel and staff, and it is impossible for the pivots to strike a blow on the jewels. The current to be measured is led into the coil through the control spring **10**, and the ligament **15**; thereafter the circuit is carried by the frame **11** at the top and by the insulated arm **17**

at the bottom. The zero is controlled by the arm **12**. Attached rigidly to the coil is a light pointer **8**. The coil **1** is mounted slightly eccentric to the axis **4** so that its weight balances the weight of the pointer **8**, a final adjustment of balance being made by the position of the small sliding weight **9**. This construction avoids the necessity of a counterweight tail and counterweight usually previously employed and therefore enables the weight of the whole moving system to be kept to a minimum, thus the controlling forces may be small and the pivot points very fine, and therefore the internal resistance of the instrument can be high without introducing objectionable mechanical delicacy or friction errors. The core **6** is held by the screw **14** to the rigid frame **13**, which, in turn, is attached to the magnet and combines the whole moving system into a unit. To this new design has been assigned the Registered Trade Mark "**Resilia**". Fig. 16 shows the moving system separated from the magnet, while Fig. 9, page 12, shows the system in position with the magnet, inside its case.

Length of Scale.

The brief explanation of the considerations entering into millivoltmeter design will make it clear that it is desirable to keep the total weight of the moving system as low as possible. This condition obviously tends to limit the length of the scale. For a given angular movement, the longer the scale the longer must be the pointer, and the longer the pointer the heavier is the necessary section of the material to give requisite strength and stiffness, and therefore, added to the additional length, the total weight of the pointer increases approximately with the square of the length of the scale. Like any other engineering design, the ultimate solution is in the nature of a compromise. If a very small scale is used the moving system will be light and therefore the friction errors small, but it will not be easy to make very fine readings. On the other hand, if the scale is made very long the possible friction errors are not only greater, due to greater weight, but are also magnified in proportion to the length of scale, and therefore, although closer temperature readings may be made, the intention may be defeated by the increase in friction errors. To take a numerical example, consider first a scale of length 5 inches (127 mm.) and assume it to be scaled from 0° to 1050° C. (32° F. to 1922° F.), it would be possible, when close to the instrument, to read at a glance to within 10° C., or, with great care, to 2° C., and it is not easy to make the instrument so that the friction errors shall be less than say 2° C. This condition represents about the best that can be done with careful workmanship on the small scale, and it will be seen that the friction error and minimum reading are of the same amount. On the other hand, we may consider an instrument having a scale of length 10 inches (254 mm.) calibrated for the same temperature range. Without any special magnifying device this can be read at a glance to 5° C. and with great care to 1° C., but in view of the effect of pointer weight, etc., mentioned above, without resorting to the "**Resilia**" patent construction, it would be difficult to make the instrument so that the friction error was as small as 2° C. after the instrument has had a little use under industrial conditions. It is therefore evident that for practical purposes the scale length of 10 inches (254 mm.) is the maximum that need be considered, and any special magnifying device will be useful mainly to make the fine readings easier at greater distance. It is fortunate that in the majority of industrial temperature measurements (apart from laboratory or research work) temperature readings as close as 2° C. are quite unnecessary, it is not possible to hold the furnance or process to anything like such fine limits and the inequalities of temperature between one part of a furnace and another are also probably much larger than 2° C.

Various devices have been proposed and used from time to time to increase the openness of scale, for instance, an instrument with a mechanically " set up " zero. In an instrument of this kind the true zero is not visible on the scale, the pointer is resting against a stop and is resisting a certain amount of the spring control when the temperature is below the visible portion of the scale. It is obvious that in an instrument of this kind the sensibility must be higher in order to get the more open scale because a given temperature change must move the pointer through a wider angle ; either the resistance as a whole must be lower or the instrument more delicate, and that method has the great disadvantage that the true zero cannot be verified, and therefore any change in the force of the controlling spring cannot be

corrected. Further, the reading cannot be set, when disconnected, to the cold junction temperature in the manner indicated as desirable and customary on page 29.

Another alternative is an electrical "set up" zero. In this case the current which would flow from the thermo-couple circuit is opposed by a current as, for instance, from a cell, until it reaches a certain pre-determined figure corresponding with the temperature at the bottom of the visible portion of the scale. This again requires either a lower resistance or a more delicate instrument in order to provide the more open scale; and further, unless there is provided some certain means of checking the electrical set up, it is quite possible for change in the cell which provides the opposing current being undetected and thus introducing errors so large as to defeat the intention in using the set up scale.

Devices on these lines are very liable to lead to serious errors in industrial conditions where there are not the facilities for frequent checking of the set up devices, the simpler instruments, by sufficient length of scale, usually furnish the best solution of the problem of securing fine readings.

Accuracy, Consistency and Fineness of Reading.

These three qualities of a pyrometer are very frequently confused due to loose thinking. It is not uncommon for a user of an instrument upon which he can make readings to a single degree to assume that that is the measure of the accuracy of the instrument and to contrast it unfavourably with another instrument which can only be read as close as 2° C. It is, of course, quite possible that the latter instrument may be really the more accurate. This matter is so important that it is worth a little further study.

Fineness of reading is merely a matter of the smallest temperature value which can be read on the scale, and usually depends mainly upon the length of the scale, the fineness of the pointer, and the distance between the observer and the scale. This latter factor can often be improved by the use of a magnifier, see Fig. 1 (frontispiece).

Consistency is the regularity with which a reading is repeated when the temperature to which the thermo-couple is submitted is the same. It would be quite possible for an instrument to be very consistent without being accurate—for instance, on successive occasions when the real temperature was 900° C. it might read 909° C., 911°, 910° and so on. Such an instrument would not be of high accuracy but would be fairly consistent. Industrially this question is frequently of very great importance, the function of the pyrometer in such cases being to ensure the repetition of a given temperature programme.

Accuracy is the exactness with which the reading of the pyrometer as a whole accords with the true temperature of the hot junction of the thermo-couple. It is the combined result of fineness of reading, consistency, accuracy of the original calibration, very small change in the total circuit resistance, very small change in the law of the thermo-couple connecting electro-motive-force with temperature, accurate setting of the indicator (when disconnected) to the true temperature of the cold junction and absence of serious friction errors.

Calibration.

It will be evident from the foregoing theoretical notes that study of the principles governing the design of a pyrometer, and the details of the instrument, will be well repaid by increasing efficiency of the pyrometer service. It is desirable, on every large installation, that provision should be made for periodical checking of the calibration and general condition of the installation. Temperature measurements are so important that it is not wise to assume the accuracy of the instrument for a long period without some means of checking. Provided the circuit conditions are properly arranged, with clean and certain contacts at the various points where the circuit is broken and re-connected, and also that the indicating or recording instrument is of a robust type in good order, then the parts requiring the most frequent attention will obviously be the thermo-couple and its sheath, as these are necessarily subjected to the destructive effect of the temperature to be measured, and this effect may be relatively rapid when the temperatures are high. Comparison against a spare or reserve thermo-couple is one of the simplest and quickest checks which can be made, and for this reason it is

alway desirable to have one or more spare thermo-couples on every installation. With the **Foster base metal thermo-couples** this desirable condition can be arranged at very small extra cost. For installations in England we have a carefully worked out system of maintenance contracts whereby we undertake periodical visits, checking and calibration of all instruments, together with the supply of all necessary renewal spares and sundries to maintain the installation in full working order.

Hints on the Use of Pyrometers.

1. Based on standard electrical practice the best working range of any instrument is between 60% and 85% of its maximum. The electric circuit of a pyrometer should be handled and protected as carefully as a circuit for light or power, with the additional caution that metallic contacts on switches, etc., must be very good owing to the low voltages available. If the reading of a pyrometer fluctuates it indicates a break in continuity of the circuit or the insulation. Starting with the thermo-couple stem, shaking or moving successively the different parts of the pyrometer will show, by increase in fluctuation, the point where the fault lies.

2. Always use an outer sheath when advised by instructions, particularly on continuous work over 650° C. (1202° F.).

3. The hot junction of the thermo-couple (at the tip) must reach the temperature to be measured, therefore sufficient insertion should be given (see special instructions with each outfit). In general the depth of insertion in the uniform temperature zone should not be less than eight times the diameter of the thermo-couple stem or its sheath. In furnaces with thick walls, however, the inner part of the wall is at a high temperature and may be counted in the depth of insertion. Unnecessary insertion is costly in thermo-couples, sheaths and other renewals.

4. Fix the indicator or recorder in a cool, clean place, and in a good light. Vibration will not hurt the indicator, but if very severe it may spoil the record of a recorder.

5. Set the indicator or recorder (when disconnected) to the "cold junction" temperature (see instructions with each pyrometer). This is essential for maximum accuracy.

6. If in doubt of the accuracy, get the furnace steady, note the reading, take out the old stem, insert a new one, again note the reading, then replace the old stem and note the last reading, of course allowing time for the stem to reach a steady temperature in each case. Compare the second reading with the average of the first and third, thus cutting out any slow rise or fall in the furnace temperature.

7. In comparing two separate pyrometers be sure that they are both measuring the same temperature. See that the stems are close together in a steady furnace or bath.

8. To check a pyrometer when no other instrument is available take a "freeze point" test of a suitable temperature (see table below). Insert the stem, protected by a sheath, into the melt. Do not let the sheath touch the sides or bottom of the vessel. Allow the melt to cool slowly and uniformly; when it reaches the "freeze point" the temperature as shown on the indicator or recorder will remain steady for a considerable time. The reading should be noted and compared with the standard temperature in the table below. (See notes on depth of insertion in paragraph 3 and "cold junction" in paragraph 5).

9. See notes in paragraph 1.

10. Always keep at least one spare of each type of stem and sheath used. When ordering spares or otherwise corresponding about the instruments, quote the type and serial numbers marked upon them.

11. STANDARD TEMPERATURES.

Material.	*Phenomenon.*	° C.	° F.
Copper	Freezes (reducing atmosphere)	1083	1981
Common Salt (pure)	Freezes (very good test)	800	1472
Pure Lead	Freezes	327	621
Water	Boils (normal air pressure)	100	212
Water	Freezes	0	32
Mercury	Freezes	—39	—38

J. W. Vernon & Co., Ltd.
Printers,
St. Albans, Herts.

FOSTER INSTRUMENT Co.
LETCHWORTH HERTS., ENGLAND.